The Jiles–Atherton Hysteresis Model

Magnetic hysteresis originates from the alignment of electron spins into magnetic domains and the reorganization of such domains under the influence of an externally applied magnetizing field. In the Jiles–Atherton model, for each domain there is a reversible rotation and an irreversible rotation, which corresponds to a reversible and irreversible magnetization. In a magnetic material without hysteresis losses, there is only a reversible part of the magnetization, usually modeled with a relative permeability or with a reversible B-H curve. The Jiles–Atherton hysteresis model includes a nonlinear relationship between the change in magnetization $\mathbf{M}$ and the change in the magnetizing field $\mathbf{H}$. The magnetic flux density $\mathbf{B}$ follows from the relation

$$\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M})$$

The Jiles–Atherton model is a phenomenological model based on several parameters. The version available in COMSOL Multiphysics is full vectorial and anisotropic (see Ref. 4 and Ref. 5) and is based on the following five parameters:

- Magnetization reversibility: $\mathrm{c_r}$
- Saturation magnetization: $\mathrm{M_s}$
- Domain wall density: a
- Pinning loss: $\mathrm{k_p}$
- Interdomain coupling: α

These quantities are second-order tensors, something that is not reflected by the equation notation here and in the graphical user interface.

The interdomain coupling parameter is used for defining the effective magnetic field $\mathbf{H}_e$, which is the field that is assumed to affect the magnetic moments on a microscopical level:

$$\mathbf{H}_e = \mathbf{H} + \alpha \cdot \mathbf{M}$$

The saturation magnetization and domain wall density determine the anhysteretic part of the material behavior, which in this implementation follows the Langevin function,

$$L(x) = \coth(x) - 1/x$$

through the formula for anhysteretic magnetization $\mathbf{M}_{\mathrm{an}}$:

$$\mathbf{M}_{\mathrm{an}} = \mathrm{M}_s \cdot L(\mathrm{a}^{-1} \cdot |\mathbf{H}_e|)\frac{\mathbf{H}_e}{|\mathbf{H}_e|}$$

where $\mathrm{M_s}$ and a are available as diagonal matrices (Ref. 4). The use of the Langevin function should be interpreted as applied component wise.

The magnetization reversibility, $\mathrm{c_r}$, affects the degree of anhysteretic versus hysteretic behavior. If it is set to unity, the model is purely anhysteretic.

The remaining parameter, $\mathrm{k_p}$, controls the pinning and hysteresis of the magnetic moments.

Given the parameters above, the key equation in the Jiles–Atherton model determines the change in the total magnetization $\mathbf{M}$ caused by a change in the effective magnetic field as

$$d\mathbf{M} = \max(\chi \cdot d\mathbf{H}_e, 0)\frac{\chi}{|\chi|} + \mathrm{c_r} d\mathbf{M}_{\mathrm{an}}$$

where the auxiliary vector χ is defined as

$$\chi = \mathrm{k_p}^{-1} \cdot (\mathbf{M}_{an} - \mathbf{M})$$

The Jiles–Atherton hysteresis model is mainly suitable for time-dependent studies, but it also supports stationary parametric simulation. The latter is especially useful if the material is starting from a magnetized configuration that is not the solution of a

previous transient study. In the user interface, it is possible to select the initial value of magnetization, in which case the initial magnetic field is set accordingly.

It is implemented for the following physics interfaces: Magnetic Fields (based on vector potential); Magnetic Fields, No Currents (based on scalar potential); and Rotating Machinery, Magnetic (mixed vector and scalar potentials).

The internal state variables are discretized directly in the Gauss points, and an auxiliary variable is added to the same domain also for aiding support to simulations with moving domains.

The order of Gauss point discretization can be selected in the **Discretization** section under the **Magnetic Field** section. For the Gauss point discretization order, the default is **Automatic**. This default sets the Gauss points discretization order depending on the order of the parent physics. If the parent physics variable has order n, the Gauss point order is $2(n–1)$. It is good practice to test that the results do not change significantly when using a Gauss point discretization of order $2n$ since a good discretization order depends on the kind of magnetic potential, mesh element shape, and space dimension, rather than the pure mesh size. For an example, see:

Vector Hysteresis Modeling: Application Library path
ACDC_Module/Verifications/vector_hysteresis_modeling