

# Checking Remanence Issues with New Hysteresis Model

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**R**emanence is what is left when all current is removed, and there is still some flux density left in the iron core. This is often the case with a close path for flux density, especially in U or E shape devices.

To get rid of this effect, it is some time useful to add a so-called remanent airgap. This paper explains what we have incorporated into Flux to model this effect due to hysteresis. The second part describes how our model was validated. In the next part we will see another effect of remanence on the starting current in transformers.

## ■ The Jiles-Atherton hysteresis model

In order to take account of hysteresis, there are traditionally 2 types of model: Preisach and Jiles-Atherton. We decided to implement the Jiles-Atherton vector model under flux with isotropic property. Magnetization (M) is defined by the sum of a reversible part  $M_{rev}$  plus an irreversible part  $M_{irr}$ .

$$M = M_{rev} + M_{irr} = (1-c)M_{irr} + cM_{an}(H_e)$$

$$M = M_s \left( \coth \frac{H + \alpha M}{a} - \frac{a}{H + \alpha M} \right)$$

$$\frac{dM}{dH} = (1-c) \frac{M_{an}(H_e) - M_{irr}}{k\delta - \alpha(M_{an}(H_e) - M_{irr})} + c \frac{dM_{an}(H_e)}{dH}$$

Figure 1: Jiles-Atherton equation for hysteresis.

The model is fully characterised by 5 parameters:

- Ms: saturation magnetisation (in A/m)
- a: shape parameter for anhysteretic magnetization (A/m)
- k: pinning coefficient (A/m)
- c: reversible wall motion coefficient
- $\alpha$ : mean field parameter representing inter-domain coupling

## ■ Determination of Jiles-Atherton coefficients using our new tool

What data are needed to determine these 5 parameters? In fact, we need the static hysteresis curve. One curve is enough to extract the data, but if possible, it is better to get a full hysteresis curve for each level of flux density. We developed a specific tool to extract the data. This tool is available on our Flux user portal - Gate in the 2D example section. It is based on genetic algorithms.

1. Select B(H) curve
2. Choose mode
3. Click on [Find out parameters]
4. Create python file
5. Try new values

Figure 2: CEDRAT's tool to extract Jiles-Atherton hysteresis coefficients.

From the tool to extract parameters, you can very easily load your initial data (B versus H values). There is a button to **run automatic parameter extraction**. Subsequently, the initial curve and the model are superimposed. At this stage, it is also possible to slightly modify the coefficients and directly observe the impact on the reconstructed curve. Once you are happy with your model, there is a button to **create a python file**, which can be used later by Flux to import the material.

The advantage of this dedicated tool is the **simplicity of coefficient extraction**.

## ■ Validation of the model

In order to test this new vector model, we applied it to an international work shop case called TEAM 32. The reference can be found on the dedicated web link (<http://www.compumag.org/jsite/images/stories/TEAM/problem32.pdf>). The case is defined by 2D geometry.

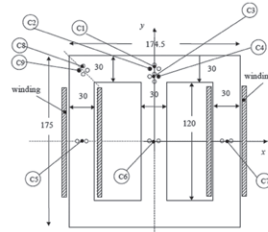


Figure 3: Structure of device fitted with pick-up coils (dimensions in mm).

It is supplied by two sine voltage supplies with a shift angle of 90°.

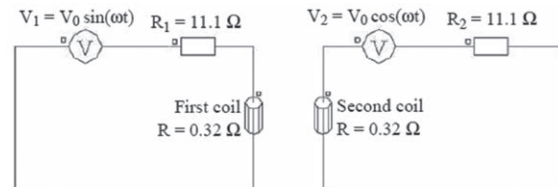


Figure 4: Circuit (V0=14.5 V, f = 10 Hz).

The flux density is measured at different locations (see figure 3). Magnetic material property is defined with the new hysteresis vector model. We assumed the JA coefficients with the corresponding values:  $M_s = 1.33 \times 10^6$  A/m,  $a = 172.856$  A/m,  $k = 232.652$  A/m,  $c = 0.652$  and  $\alpha = 417 \times 10^{-6}$ . We have solved 4 periods with 200 steps per period. The steady state was reached in the second period. The simulation lasted one hour and 23 minutes on a PC with Intel® i7-3740QM at 2.7 GHz CPU with 8 cores. We can observe currents in the two coils, and also different flux density components.

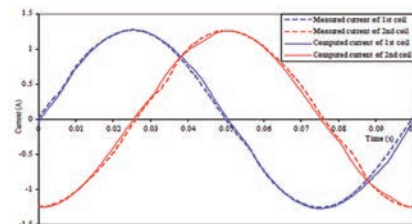


Figure 5: Currents in the 2 coils.

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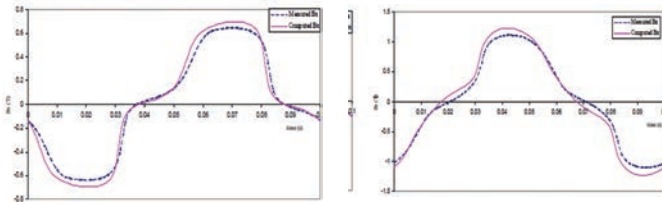


Figure 6 : Bx and By component of Flux density at point P2 (pick-up coils C3 and C4).

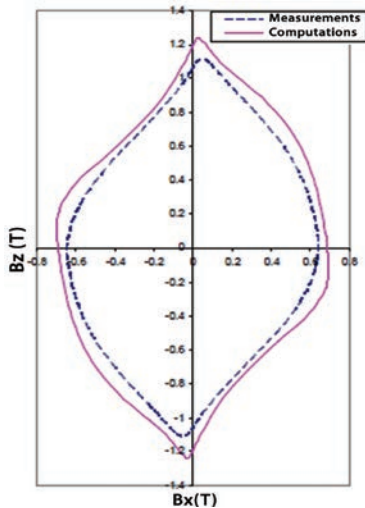


Figure 7: Bx-By at point P2 (pick-up coils C3 – C4).

The results are displayed in figures 5 and 6. The results match the reference result. The effect of hysteresis has been taken into account accordingly.

### Impact of remanence on starting current in a transformer

To show the benefit of using such a hysteresis model, we performed a study on starting current in a transformer. The transformer is an ideal single-phase transformer.

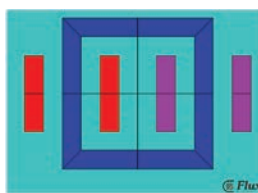


Figure 8: Geometry.

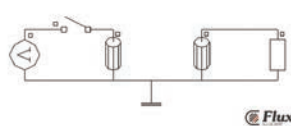


Figure 9: Circuit.

We supply only the primary, and the secondary is considered as open circuit. We propose to look at starting current, starting from scratch and also starting after a stop.

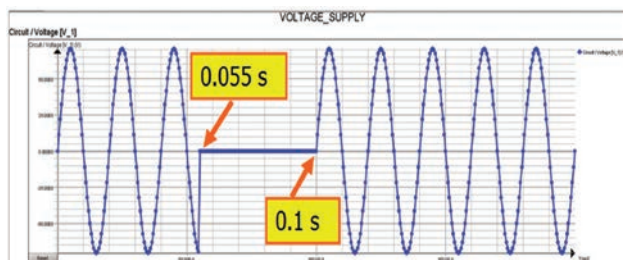


Figure 10: Voltage supply.

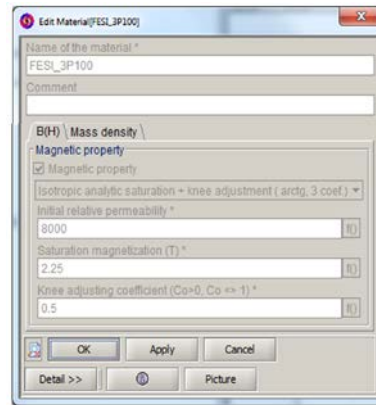


Figure 11: Description of equivalent B(H) property with or without hysteresis.

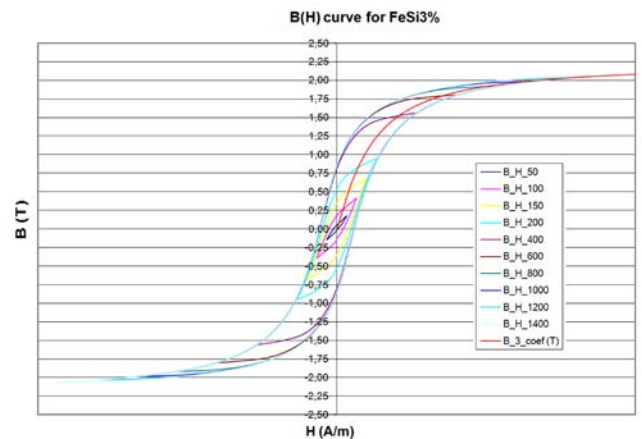


Figure 12: Hysteresis curve for FeSi 3%.

The result is very interesting. We can see that we do have starting current. When starting from scratch with the 2 different B(H) models, we have the same starting current, which is expected. When restarting after a stop, there is a huge difference. With hysteresis, the magnetic core is still magnetized, as shown in figure 13, which modifies initial inductance and develops high starting current.

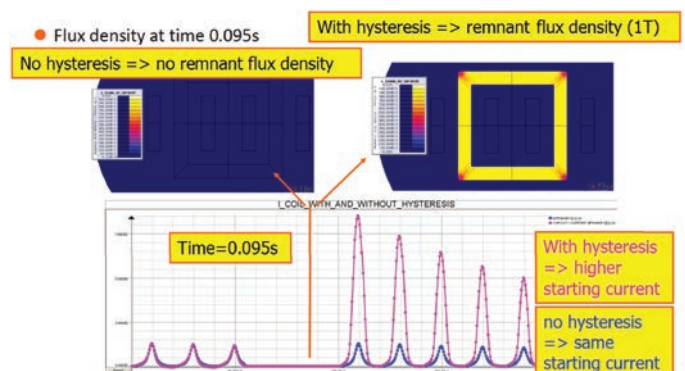


Figure 13: Starting current and B color shade.

“ Induction treatment has been considered as a key industry and CEDRAT delivered its first magneto-thermal analysis tool under Flux 2D in 1986. ”

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In some applications, in order to limit starting current or remaining force with no current, one strategy is to include a small airgap called a remanent airgap. The question may become "What is the ideal thickness of this airgap?" We added an airgap into the geometry (on the right part) and ran a parametric analysis for different airgap thicknesses. The result on the starting current appears in figure 14. We can see that with an airgap greater than 0.1 mm almost all of these higher starting currents can be removed.

### Conclusion

This paper has shown a new model of hysteresis being implemented under Flux. This model, based on the Jiles-Atherton model, allows remanence to be represented, and produces interesting results. Furthermore, a dedicated tool allows easy extraction of the 5 parameters needed to represent B(H) behavior. All in all, this functionality is easy to use. The benefit is greater accuracy and new computation options.

NB: the model implemented is a static hysteresis model, and does not represent the effect of frequency. It means, for instance, that the model should not be used to compute iron losses in motors. This model is a first step toward full hysteresis. An enhanced model will come with the next Flux v12.1 version.

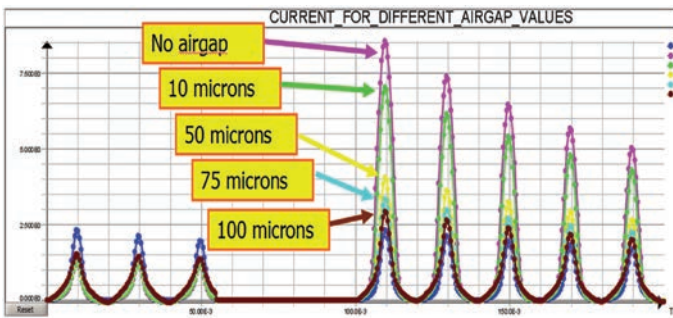


Figure 14: Starting currents for different thickness of airgap.

With Flux we can also display the B color shade, with the same Flux density range for the different airgap values at the same time. We can see that the remanent flux density decreases as airgap thickness increases.

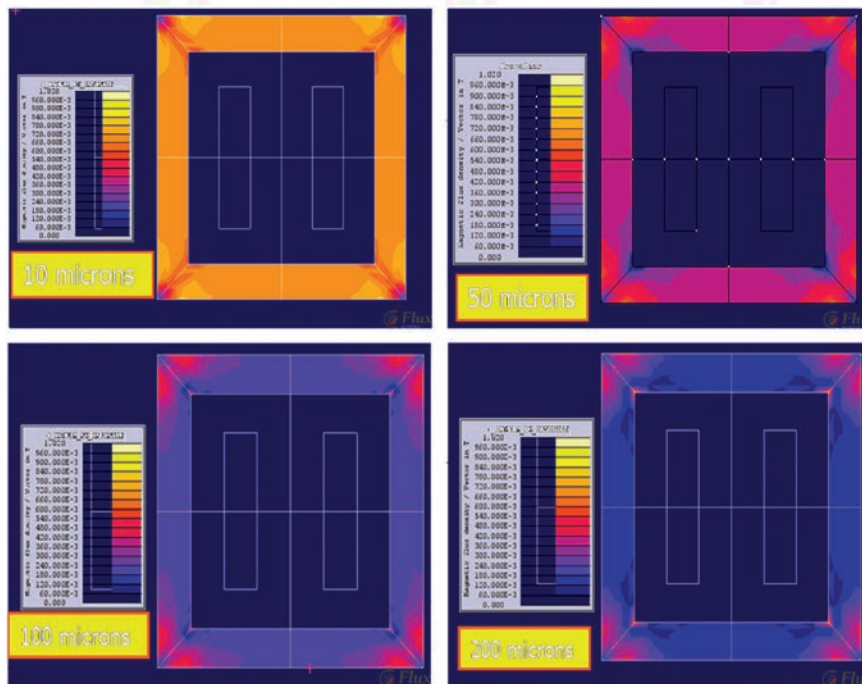
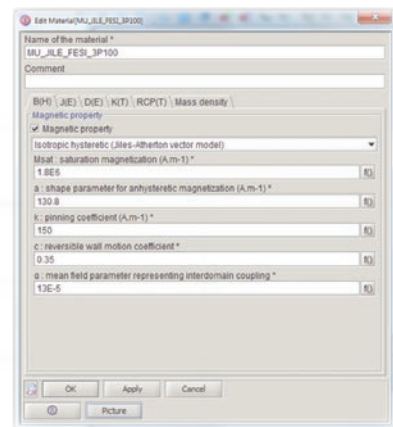


Figure 15: Flux density at time 0.095s (no current) for different thickness of airgap.