Control-oriented hysteresis models for magnetic electron lenses

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I. Electron microscopes

Automation of electron microscopes is complicated by hysteresis present in the magnetic electron lenses. By mathematical analysis of hysteresis-models, we want to design transient input trajectories that result in a minimal settling time and a reproducible steady-state end value of the magnetic field. Hysteresis and magnetization dynamics are characterized by means of experiments on a setup containing a magnetic electron lens (Fig. 1). Developed strategies can be directly validated on a commercial electron microscope. By analysis of the obtained image-series we ensure that the hysteresis models fit the application.

Magnetic electron lenses consist of a coil (800 turns) surrounded by a solid ferromagnetic lens-yoke (NiFe). In an electron microscope, an electron beam is positioned on a sample with the help of a magnetic field of which the amplitude is controlled by the current applied to the lens coil [± 2A]. Control is in first instance not image-based since differences in input current of more than 0.1% already result in an unusable image (Fig. 1).

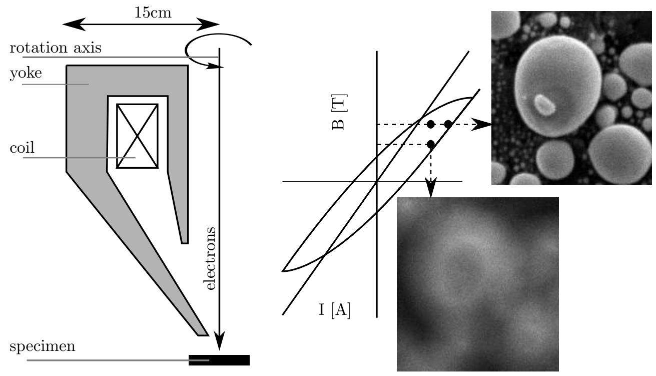

Fig. 1. Left: Cross-section of a magnetic electron lens. right: Influence of hysteresis on image-quality; the same input current results in a completely different image.

II. Model requirements

Due to limitations of the applied magnetic field strength in combination with the size of the lens-yoke, the material can never be completely saturated, the major loop can never be reached and first order reversal curves (FORC's) are not available.

We optimized the parameters of the Coleman-Hodgdon model [1] which accurately predicts for low frequent and symmetric excitations. As mentioned in [2] this model cannot deal with oscillations situated around an offset, since the minor loops always drift towards the anhysteretic curve of the model. However, accommodation is observed in user applications that repeatedly switch between two positive lens currents. The scenario is reconstructed on our setup. Figure 2 shows the response of the magnetic lens to switching input currents. After 20s a constant offset current (I=0.7A) is applied (200s). The response of the magnetic field (normalized) shows aftereffects (lower left plot). Then 200s of a square-wave is applied (f=0.1Hz, I=0.7 ±0.1A) followed by 50s of rest and a square-wave of which the frequency is 5 times as low. It is observed that the number of switches influences the drift of the minor loop; here accommodation is the dominant effect.

To be able to predict the observed effects, we will present an evaluation of accommodation-models described by the authors of [2] tested on the experimental data.

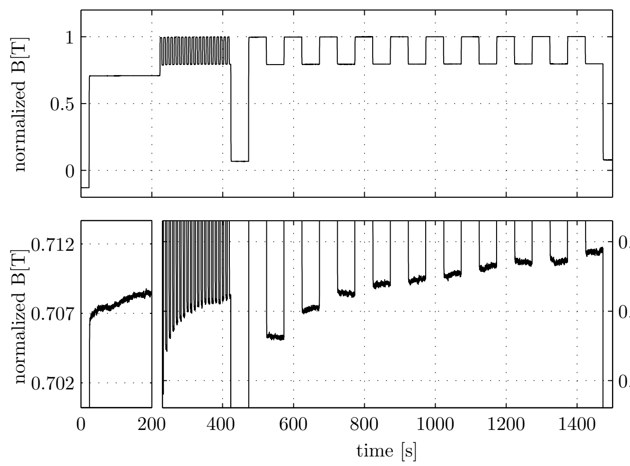

Fig. 2. Measurement of magnetic electron lens response to switching input currents. upper: normalized, lower: zoomed versions.

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