Quasi-static variations of the ambient magnetic field and their implications on TEM practice

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It is well known that variations of the ambient magnetic field (stray field) may have disastrous impact on operating an EM. For AC stray fields, especially for f = 50 Hz, EM manufacturers usually give detailed specifications of tolerable limits for the diverse operation modes: HRTEM, STEM, EELS etc. For low-frequency AC stray fields reliable specifications are, however, hardly to obtain. These stray fields, sometimes called quasi-DC (f < 15 HZ), are often originated by the motion of large ferromagnetic objects nearby, such as elevators, cars, trucks or trams. High- and low-frequency stray fields have in common that the magnetic ***B***-field oscillates around a certain fixed value (irrespective of the long-term variations of the earth magnetic field). The microscope can be aligned for this fixed value of ***B***, and the question of tolerable limits is treated with respect to blurring during the time interval which is needed to record a HRTEM image, a STEM image, an EEL spectrum etc.

New problems arose with the emergence of techniques like e.g. swept field NMR where 10-Tesla magnets (or bigger) are powered up und down within hours or days. Even when such equipment is placed at some considerable distance to EM labs, slow ***B***-field variations may be imposed which are much higher than the peak-peak values considered as tolerable limits for AC stray fields. We call these variations quasi-static. They are obviously negligible during the recording of a single HRTEM image (a few seconds). However, they may be a problem during longer recordings (STEM, EELS) and in all those cases where the alignment of the microscope or EELS spectrometer becomes obsolete within hours/days when the ambient ***B***-field changes quasi-statically.

For a Tecnai F30 G2 (*FEI*) with motorized apertures and a GIF 2001 (*Gatan)* operated at 300 kV, we investigated the influence of quasi-static ***B***-field variations in detail. Laboratory layout and coordinate axes are sketched in Fig. 1. Helmholtz coils which are installed along the edges of the laboratory were used for magnetic field generation instead of compensation. We investigated the influence of $\Delta\boldsymbol{B}$ on: beam, image, focus, 2-fold astigmatism, coma-free axis, and 3-fold astigmatism in HRTEM mode; focus and beam in STEM mode; zero-loss peak shift in EELS (EFTEM unconsidered). Thereby, the approach was fully pragmatic and oriented to the needs of everyday work —with no particular regard to electron optics and column construction. Far from making claims to be complete, we choose standard situations for magnification, camera-length, spot-sizes etc.

In TEM mode the ΔB_y-component (front-back with respect to the microscope) is more influential than ΔB_x (left-right) and ΔB_z (down-up). The beam position shift is drastic, but in practical work the beam will always be centered again when drifting away slowly. When doing this, the influence on 2-fold astigmatism, coma-free axis and 3-fold astigmatism is not significant, even when applying ΔB = 45 mG. The maximum image shift is 0.13 Å/mG, which correlates well with the specification given by the manufacturer [1] for the tolerable limit of 3.5 $mG_{p\text{-}p}$ (50 Hz) with respect to the point resolution of the Tecnai F30 (2 Å). Additionally, ΔB_z introduces a small focus shift of 40 Å/mG.

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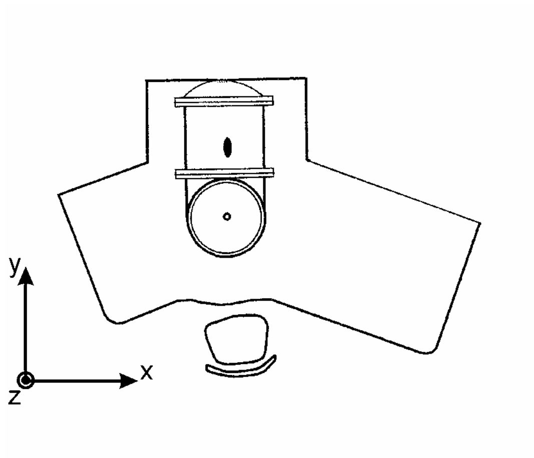
In STEM mode all components of $\Delta\boldsymbol{B}$ are equally influential. The maximum image shift (here identical with beam position shift) is 0.5 Å/mG and, hence, much larger than in TEM mode. Additionally, ΔB_z introduces a noticeable focus shift, which could not yet be quantified. Fig. 2 shows the beam and focus shifts introduced to a STEM image when applying $\Delta B_{x,y,z} = 45$ mG.

In EEL spectroscopy ΔB_x is more influential than ΔB_y and ΔB_z. The zero-loss peak is shifted by 0.7 eV/mG, with 0.7 eV being the best spectral resolution attainable with the equipment in use. Fig. 3 shows the shifted zero-loss peak when applying $\Delta B_x = 15$ mG.

In conclusion, a quasi-static B-field variation of 1 mG/min is harmless for HRTEM and STEM image recording, but may seriously compromise registration of EEL spectra. When the total variation stays below 50 mG over a day, re-alignment of the microscope (except the EEL spectrometer or GIF) is not necessary within this time.

1. Tecnai 30 Transmission Electron Microscopes: Pre-Installation Instructions, First edition, FEI Company 1998.



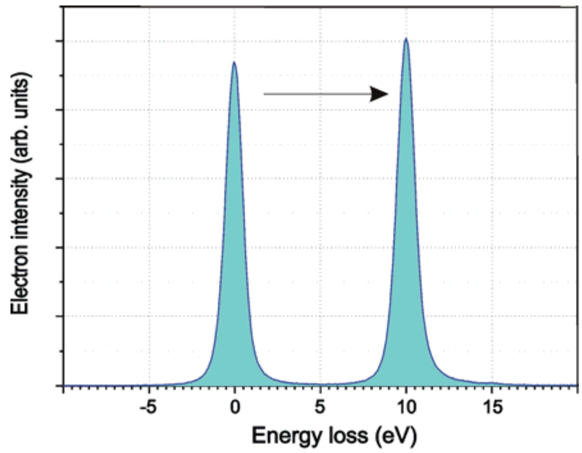


Figure 1. Arrangement of the coordinate axes with respect to the microscope.
Figure 2. Shift of the EELS zero-loss peak when imposing $\Delta B_x = 15$ mG during spectrum acquisition (left: before, right: after).

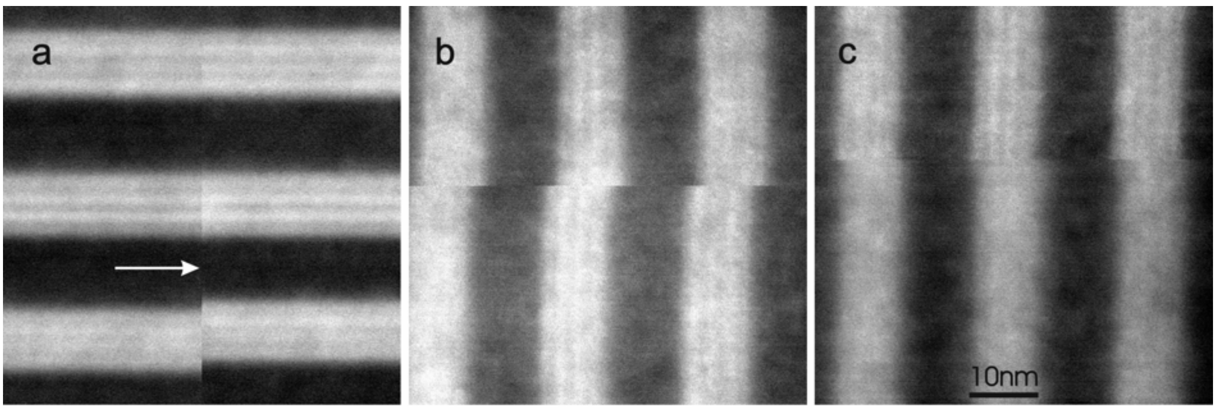


Figure 3. Image shift and focus shift in STEM mode after imposing a) ΔB_x, b) ΔB_y, and c) $\Delta B_z = 45$ mG. a) is split in two images, an undisturbed one (left) and one with the field imposed during acquisition (arrow). For the images in b) and c) the field was imposed during single acquisitions.

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