Analytical and Numerical Calculation of Multipole Fields of a Wire Lens for an Aberration Corrector

Tomonori Nakano
Hitachi, Ltd. Research & Development Group,
1-280 Higashi-Koigakubo, Kokubunji-shi, 185-8601, Japan
tomonori.nakano.ut@hitachi.com

Yu Yamazawa
Hitachi High-Technologies Corp.,
Ichige, Hitachinaka-shi, Ibaraki 312-8504, Japan

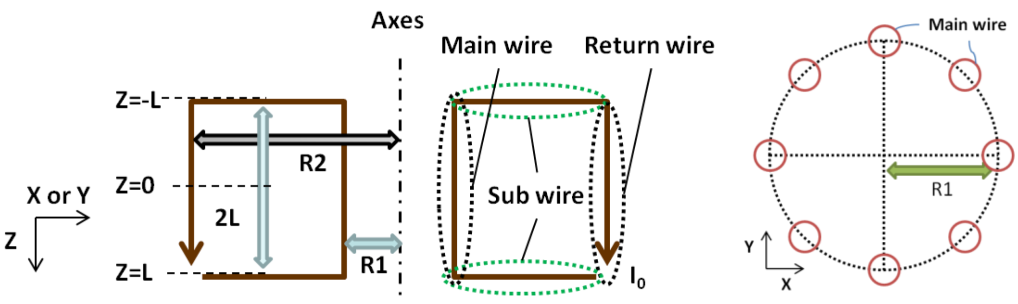
For high-resolution observation and material analysis, TEM/STEM with an aberration corrector[1] has been widely used. Most aberration correctors consist of magnetic poles made of a magnetic material exhibiting magnetic hysteresis and inhomogeneity. Such aberration correctors therefore have difficulties in controlling repeatability and uniformity of correction conditions. To resolve these issues, a setup called a "wire lens," in which current flows in symmetric parallel lines, was proposed[2]. The previous studies show that a wire lens can excite various types of multipole fields and correct aberrations. These field distributions, however, are assumed to be generated by infinitely long wires. In this study, multipole-field distributions generated by wire lenses with finite lengths were analyzed in comparison with those generated by ordinary aberration correctors.

A schematic of a wire lens is shown in Fig. 1. The main wires are only required for aberration correction; the other wires serve as current pathways. The field distributions along the z-axis, generated only by a finite length of the main wires, were evaluated first. Examples of quadrupole-field intensity are shown in Fig. 2. As half wire length *L* decreases, peak intensity also decreases, and the infinite-long-wire approximation becomes less accurate. Higher-order parasitic fields are generated around both sides of the wires. However, the integrated values of the parasitic fields are relatively small compared to those of other aberrations, so the influence of those fields is considered negligible. The quadrupole-field intensities of the sub wires are shown in Fig. 3(a). The maximum field intensity generated by the sub wires is around one-tenth of that generated by the main wires. The total field intensity of the wire lens is compared with that of a conventional multipole lens (determined by numerical calculation) in Fig. 3(b). The peak intensity of the wire lens is approximately 20% lower than that of the conventional multipole lens mainly because of the sub and return wires. It is thus concluded that the differences between the two fields can be minimized by controlling the parallel currents and designing the wire lens as a "modified" wire lens.

---

[1] H. Rose, Correction of aperture aberrations in magnetic systems with threefold symmetry. Nucl. Instrum. Meth. Phys. Res. 187 (1981) 187-199.

[2] S. Hoque, H. Ito, R. Nishi, A. Takaoka, E. Munro, Spherical aberration correction with three fold symmetric line currents, Ultramicroscopy 161 (2016) 74-82



(a) (b)

Figure 1: Schematic illustration of a wire lens: (a) Side view of wire lens and (b) top view of main wires. The wire lens consists of sub wires, return wires, and main wires alongside an axis, where *R1* is the radial distance from the axis to the main wire in the x-y plane. Also, the finite length of the line is *2L* in the z direction, and the center of the line is positioned at *z*=0 (its edges are at $z=\pm L$).

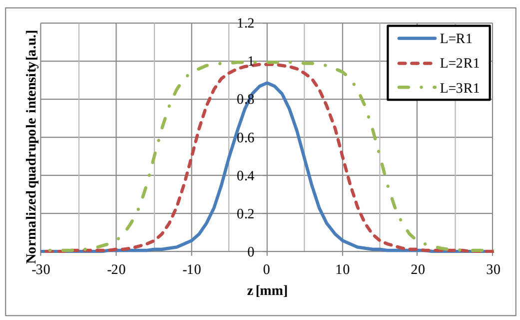
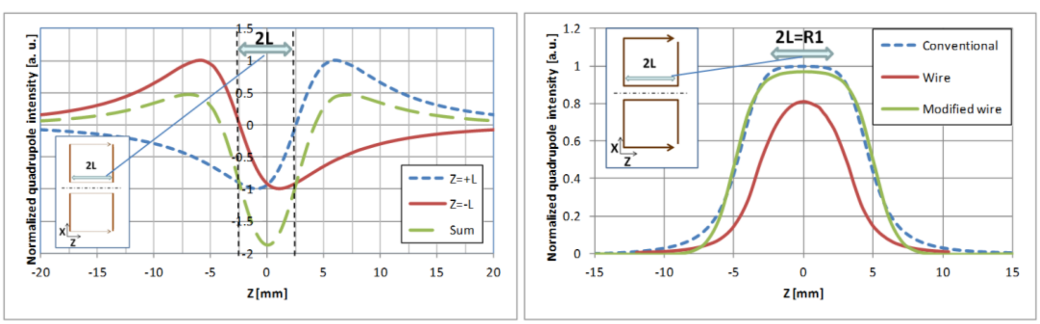


Figure 2: Normalized quadrupole field-intensity distributions generated only by a finite length of the main wires with R1=5 mm and varied length L: Multipole field intensities are defined as the coefficients obtained by a series expansion of variable ϖ and ω for magnetic-flux density. Quadrupole-field intensity is a coefficient of the ϖ term (in units "T/m") in the expansion series.



(a) (b)

Figure 3: Normalized quadrupole-field-intensity distributions for R1=2.5 mm: (a) Sub wire at *Z=-L* and *Z=+L* and (b) Comparison between a conventional multipole lens and a wire lens. Quadrupole fields of the conventional multipole lens and wire lens are calculated by numerical models. The quadrupole field of the modified wire lens, where *2L* is increased from 5 to 10 mm, is calculated by using an analytical model.