Karlsruhe Institute of Technology

CEOS Corrected Electron Optical Systems GmbH

Laboratory for electron microscopy

The SPANOCH method: A key to establish aberration correction in miniaturized (multi)column systems?

R. Janzen[1], S. Burkhardt[1], P. Fehlner[1], T. Späth[1], M. Haider[1,2] *contact: info@dr-janzen.de*

1: Laboratory for electron microscopy, KIT, Engesserstr. 7, 76131 Karlsruhe, Germany

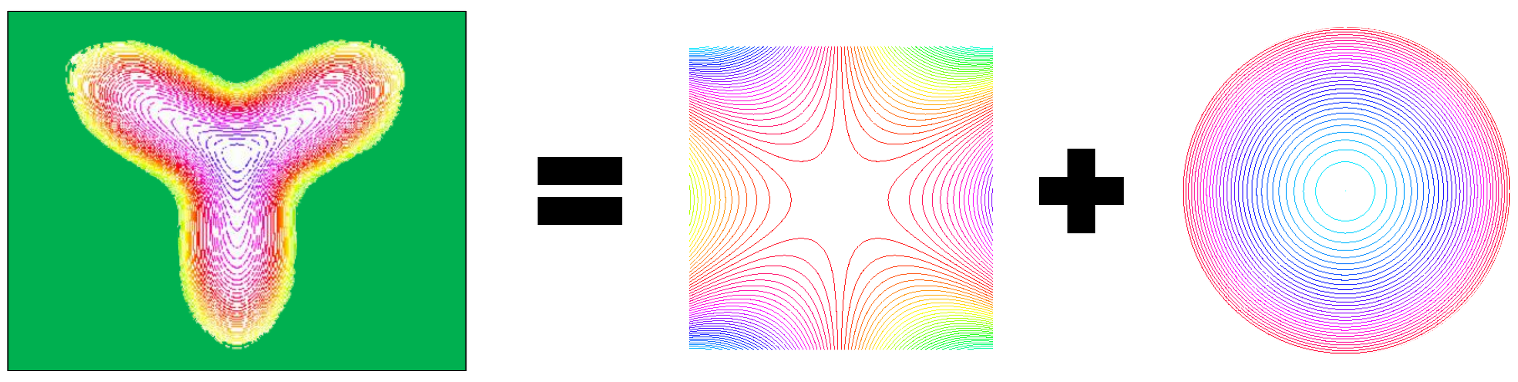
2: CEOS GmbH, Englerstr. 28, 69126 Heidelberg, Germany

Motivation

- Scherzer theorem: rotationally symmetric fields suffer from spherical and chromatic aberrations.
- Within electron microscopes correctors are meanwhile state of the art.
- These correctors can not be randomly miniaturized
  - not suitable for miniaturized single or multicolumn systems.
- We present a new concept:
  - provide multipole fields for correction purposes within a stack of thin sheets (plates),
  - as it could be produced by integrated fabrication methods.

Principle

- Holes within apertures are electron optical elements
- Superposition principle:
  - example: threefold symmetry



- The SPANOCH concept
  - We define 'SPANOCH' (sophisticated pile of apertures with non-circular holes) as a method of building a corrector out of a stack of apertures with specially shaped holes.

SPANOCH-type hexapole corrector

- Theoretical proof of principle: ray tracing study 2008
  - Problem: Test-design not adjustable
- New design: decoupling of hexapole moments and round lenses by four adjustment voltages.
- Random access to hexapole strength
- Free of second order aberrations due to double symmetry:

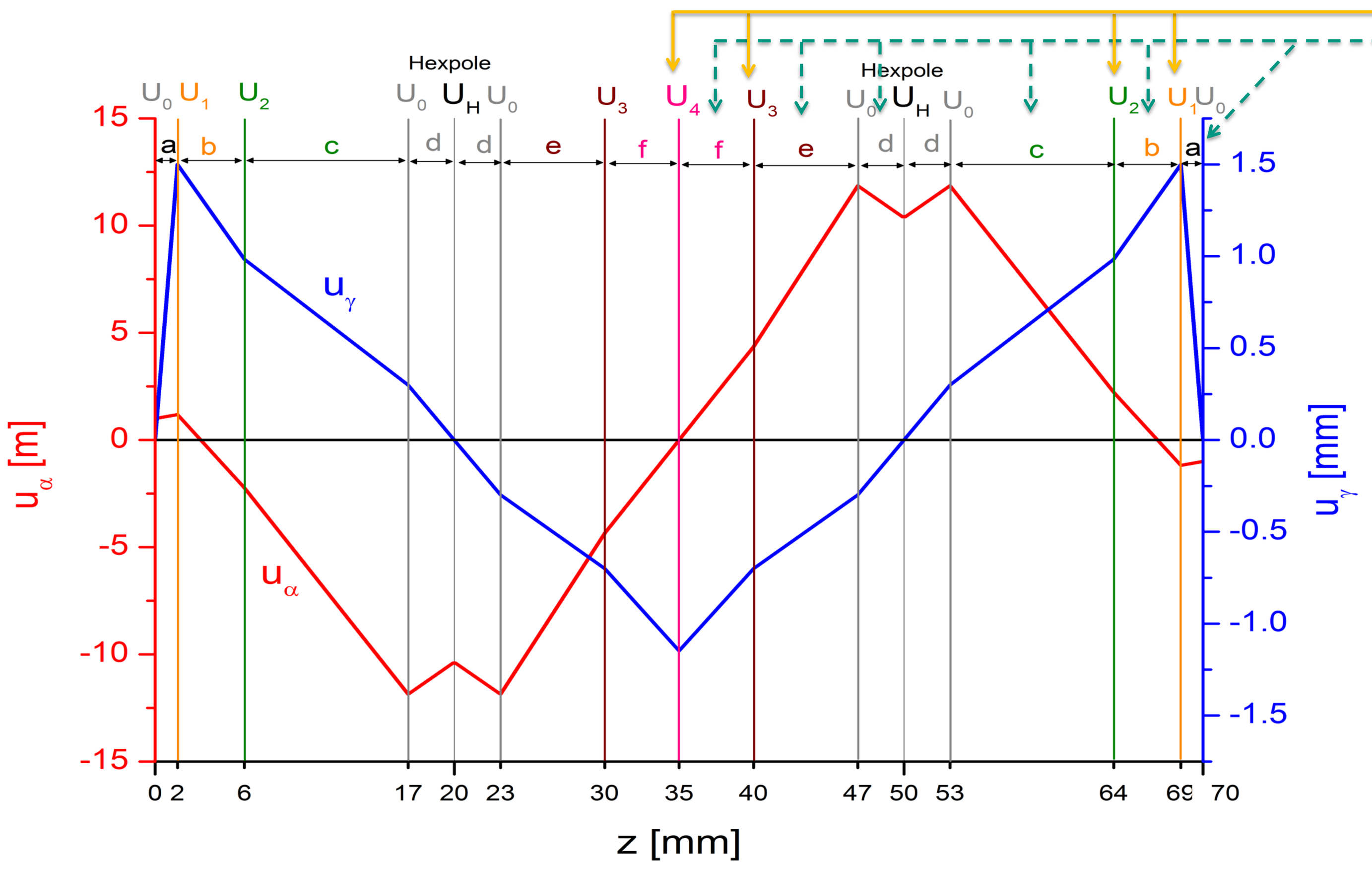
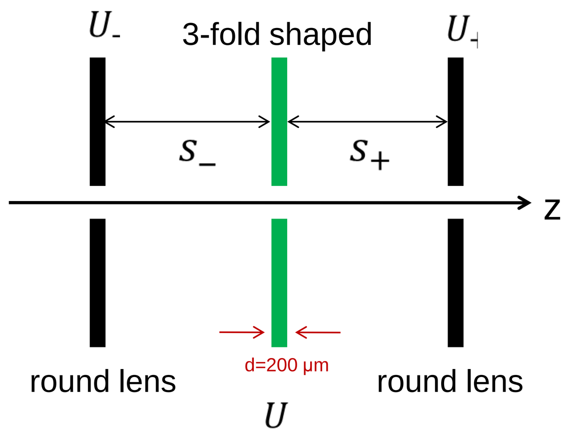


Figure 1: Sketch of the optimized design of a SPANOCH-type hexapole corrector together with the course of the fundamental rays. The z-direction is the direction of flight of the electrons. All apertures are represented by colored lines. The two apertures generating the hexapole fields by 3-fold shaped holes are marked in black. All other apertures are conventional ones having round holes. The distances 'a' to 'f' are generic parameters of the design.

Calculation methods

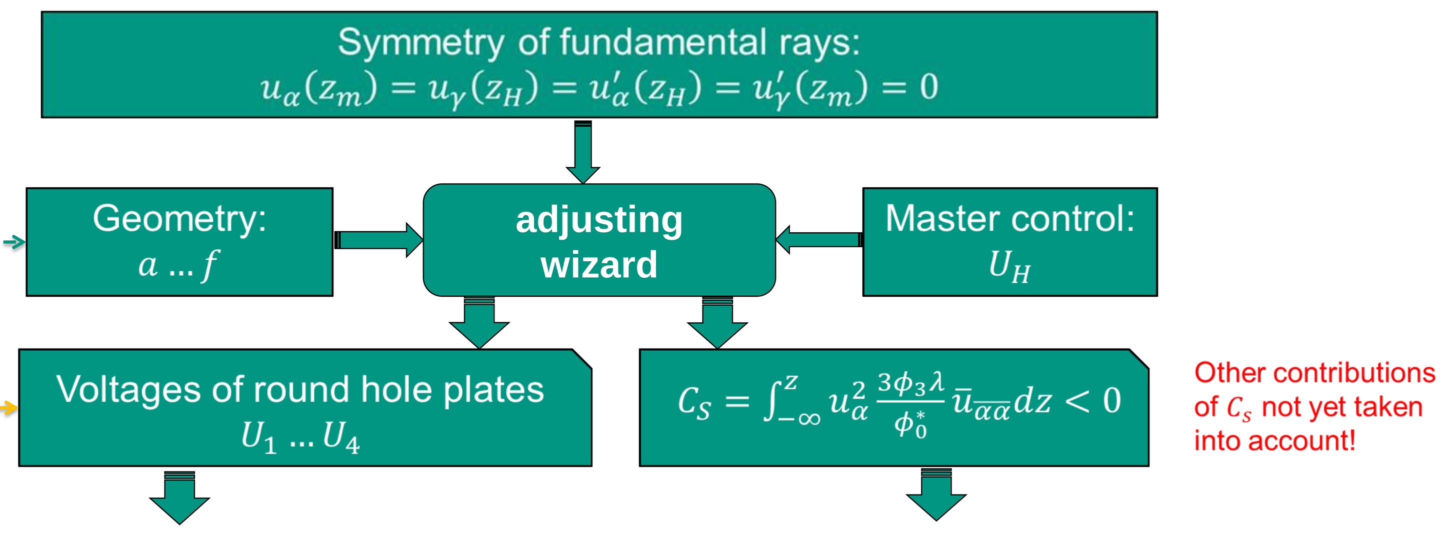
- SCOFF method used to approximate fundamental rays
- Fit of hexapole field strength ϕ_3 determined by numerical analysis of plate triplet

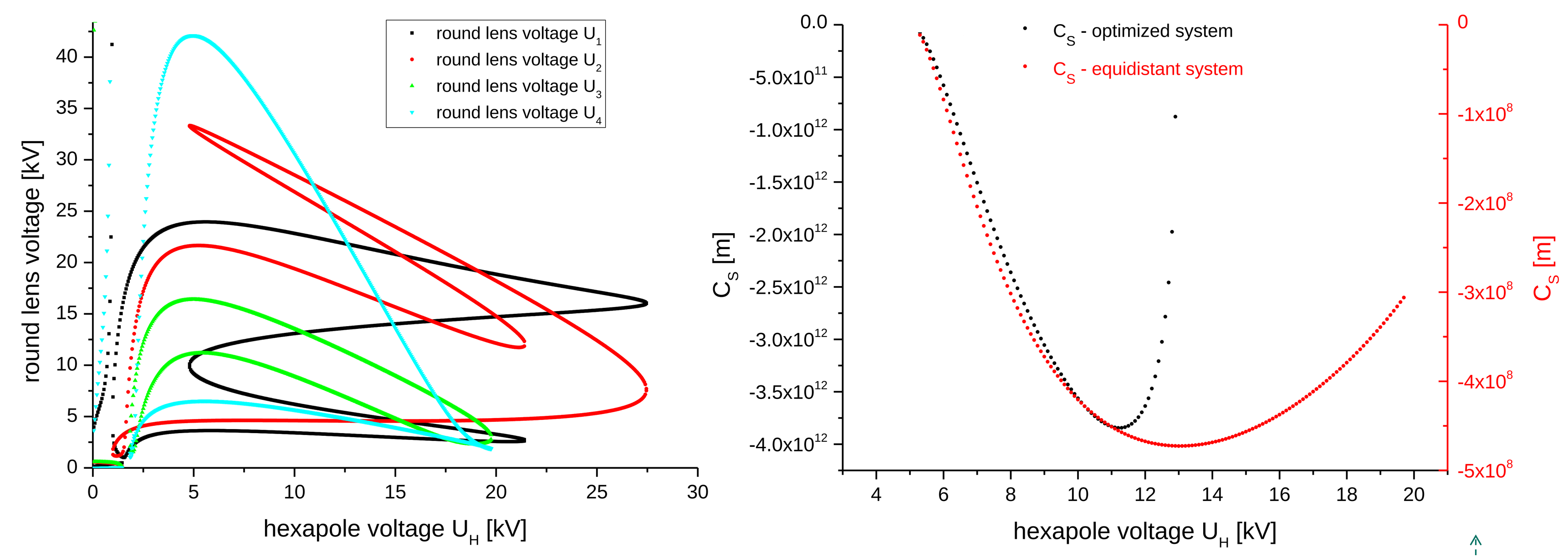
$$\phi_3(z) = \phi_{3A} \cdot \exp\left(-\frac{1}{2}\left(\frac{z-\phi_{3C}}{\phi_{3W}}\right)^2\right)$$



fit parameters	dependencies
amplitude ϕ_{3A}	field strength, radius difference
width ϕ_{3C}	radius difference
center ϕ_{3W}	thickness

- Adjusting wizard calculates adjustment voltage and correction power C_S
  - Input/output diagram:





Kernel of adjusting wizard

- Use of transfer-matrix method to calculate fundamental rays in SCOFF approximation.
  Sequence of simple lenses:
  - $M_{lens} = \begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix}$ $\quad M_{space} = \begin{pmatrix} 1 & s \\ 0 & 1 \end{pmatrix}$
  - Davisson-Calbick-formula: $f = \frac{4U}{\frac{U_+ - U}{s_+} - \frac{U - U_-}{s_-}}$
  - $\vec{r} = \sum_i M_i \vec{r}_0$

Analysis of results

- Change of parameters showed a tremendous optimization potential, e.g. distance a:
  $a \to 0.3a \Rightarrow C_S \to 10^4 C_S$
- Continuous, approximately linear regulation of C_S via hexapole voltage
- Implementable global field strengths $E < 4\,\mathrm{kV/mm}$

Outlook

- Further simulations without SCOFF approximation taking into account all contributions to C_S and to C_C will show the absolute potential of the hexapole corrector. These results will serve as initial adjustment for exact simulations.

Acknowledgement

We express our special thanks to CEOS GmbH, Heidelberg and ICT GmbH, Heimstetten for financial support.