Possible Ω Energy Filter for PEEM3

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The present note is an attempt to estimate space required for a possible Ω energy filter as a future upgrade of PEEM3. Among the advantages of a Ω energy filter are that the rest of the microscope remains on the original optical axis and that major second-order aberrations can be easily corrected [4].

Over the past years, two types of Ω filters have been designed and/or built. One type creates dispersion in the middle, therefore the optics is symmetric [2]. In fact, it has been demonstrated that it is possible to correct all but one second order aberrations ($\alpha\delta$) using double reflection symmetry [2]. Since the linear matrix is a unity matrix, in principle, no further adjustment is needed. In an other word, it is a truly transparent optical system. The drawback is that "the energy spectrum can be obtained only through the serial detection method" (quote from ref. [8]). On the other hand, this may not be a problem for PEEM3. No energy filter of this type has been built. On the other hand, at least one electrostatic monochromator employing similar optics has been built and tested [9, 10].

The other type creates an achromatic image of the object at the exit with non-zero dispersion prime. A dispersive image of the back focal plane is formed and the energy spectrum is obtained [3, 4, 6, 7, 8]. It appears that the main advantage of this type of energy filters is large dispersion [3]. Since only single reflection symmetry is maintained, more second-order aberrations are left uncorrected. At least one such filter was designed and built with sextupoles included to correct second-order aberrations [4] and one built without multipoles [8]. To the knowledge of the author, all filters of this type built up to date use edge focusing. There are two sub-types of this kind of filters. The A-type has a point image at the center and the B-type has a vertical line image [1, 8]. Usually the B-type filters require weaker focusing. From the literature collected, both types of filters have been built. The A-type filter built at the Fritz-Haber-Institut in Germany uses sextupoles to correct second-order aberrations, whereas the B-type filter(s) built at JEOL in Japan have no multipoles. The one in SMART is a direct copy of the Fritz-Haber-Institut (FHI) filter [5]. To incorporate this kind of filters (both A-type and B-type) into PEEM3 requires adjusting the position and focal length of the field lens after the separator and an additional round lens after the filter. Note that the additional lens is used to form an intermediate image of the object to make room for the aperture to be placed at the dispersive image of the diffraction plane. It may not be optimized for compactness but can be viewed as an easy solution that gives an upper bond on space needed.

In order to explore various options of layout and estimate the energy resolution of each type of filters, sharp cut-off fringe field (SCOFF) model is used to calculate both linear and nonlinear maps. A realistic design depends on a detailed model of the fringe, which is rather straightforward compared to the separator using the Schwartz-Christoffel model. Past and present experiences show that the difference in geometry predicted by the two models is rather small, with the difference in drift length on the order of millimeters and the difference in edge angle on the order of degrees [3, 4]. Comparison between SCOFF and Enge model shows that second-order terms associated with vertical coordinates are strongly influenced by the shape of the fringe field. Difference can be as large as a factor of 4. Terms that are associated with horizontal coordinates only change less than 20%. It seems that the SCOFF model can at least predict the order of magnitude of the achievable energy resolution.

Name	length (m)	height (m)	l_{ext} (m)	l_{tot} (m)	Δ^* (μm/eV)	R_{eh} (eV)	R_{el} (eV)
DR	0.10	0.25	0	**0.1**	5.0	2.4	0.03
FHI	0.46	0.19	0.49	**0.95**	23.5	0.6	0.04
FHIv	0.35	0.32	0.11	**0.46**	13.1	1.5	0.03
JEOL	0.29	0.16	0.23	**0.52**	7.1	0.5	0.02

Table 1: Parameter lists of various energy filters. DR is the one proposed in ref. [2]; FHI is the one built at FHI [4]; FHIv is an variant of FHI found by the author that has a shorter distance between the object image and the dispersion image. JEOL is one that is similar to those built at JEOL. The bending radius of all magnets is 5 cm. The bending angles of DB, FHI, FHIv and JEOL are 127°, 90°, 90° and 110°, respectively. Length is the distance between the images of the dispersion plane at the entrance and the exit. Height is the extant of the beam in the horizontal plane. l_{ext} is extra space needed for matching. l_{tot} is the total space necessary longitudinally. Δ^* is dispersion. R_{eh} and R_{el} are energy resolution limited by aberrations for the cases of full flux (low resolution) and limited flux (high resolution), respectively.

Table 1 shows the basic parameters of a few cases that may be of relevance to PEEM3. All filters are placed after the field lens after the separator. The energy resolution is defined as the ratio of the dispersion and the size of the image due to aberrations. The size of the image is estimated as the square root of the sum of the squares of major aberrations. For the case of full flux and limited flux, the fields of view are 40×40 μm and 5×5 μm, respectively. With the nominal focal length of the field lens to be 2.5 cm, the beam angle is 10 mrad (magnification is 12.5). The pencil angle is $\sqrt{1/20000\pi/4}/12.5 = 0.45$ mrad. When focal length is adjusted to match the filter, all beam parameters are scaled accordingly.

The energy filter DR has the highest degree of symmetry. As a result, only one second-order aberration is left uncorrected at the dispersion plane and three at the object plane. It has the smallest dispersion among the cases yet also requires the least amount of real estate. The resolution of 2.4 eV at full flux is probably sufficient. The filter FHI, which is the one used in SMART, produces the largest dispersion but also requires almost 1 m extra space. A variant of FHI cuts the space needed to about 0.5 m and so does the filter JEOL. Note that in ref. [7, 8] large space of parameters has been explored. Due to the lack of details in the references and the lack of time of the author, only a small subset of the parameter space has been mapped by the author. The dominant aberrations of DR at the object image are second and third order ones. Together they cause about 1 nm reduction in spacial resolution at the edge of the 40×40 μm field. Therefore, multipole correctors of are not necessary. The leading aberrations of the filters (40×40 μm field) FHI, FHIv and JEOL are 176 nm, 1760 nm and 160 nm, respectively. Clearly, multipole correctors are needed as did in the SAMRT design. Only sextupoles are needed because third order aberrations are small. The aberrations the the above cases also show that B-type filters tent to have smaller aberrations due to weaker focusing.

In conclusion, the filter proposed by Degenhardt and Rose looks most promising at the present stage. The layout of PEEM3 with such a energy filter is shown in Figure 1. The original FHI filter seems to be too bulky. The B-type filters designed and built by JEOL is also a good candidate. It will be ideal to build the vacuum chamber 50 cm longer so that option of the JEOL filter can be kept open.

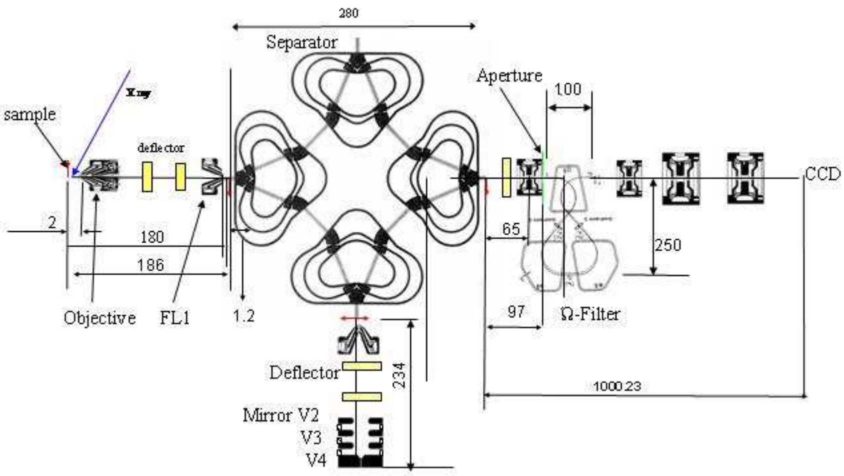

Figure 1: The layout of PEEM3 with a DR filter

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