Minutes from the FCC-ee Optics meeting of 5 of June 2015

Participants: Sandra Aumon**,** Michael Benedikt, Helmut Burkhardt, Andreas Doblhammer, Bastian Haerer, Bernhard Holzer, Roman Martin, Katsunobu Oide, Frank Zimmermann.

Phase advance matching for chromaticity correction for FCC-ee, by Bastian Haerer.

Bastian Haerer develops a chromaticity correction scheme in the arcs that he will combine with the local chromaticity correction in the IR proposed by the BINP colleagues. At the moment he focuses on a LEP-like scheme using the W Montague functions as a measure of the optics disturbance for energy deviations. W is a complex vector depending on two chromatic variables A and B, and rotating in the A-B-plane with twice the phase advance along the ring. Therefore the phase advance between the quadrupole, which is the source of the chromaticity and the correcting sextupole is very important. Since the quadrupoles of the final focus doublet are the largest contributors to the chromaticity, and therefore to the W function, the aim is to carefully match the phase advance between those quadrupoles and the first sextupoles in the arc to an integer multiple of pi. This then allows reducing the norm of the vector W iteratively with the arc sextupoles. He presented the status of the phase advance matching that he wants to apply for different chromaticity correction schemes.

The FCC-ee interleaved sextupole scheme in the arcs is designed to have a -I transformation between two members of the same family of sextupoles. Since the phase advance in horizontal plane is 90 deg. per cell two families are foreseen, and three families in the vertical plane, where the phase advance is 60 deg. per cell. As the W-vector rotates with twice the phase advance, it makes 2pi in-between two sextupoles of the same family, necessary for the iterative correction within the arc.

Bastian will compare the performance of a lattice with non-symmetric FODO cells (sextupole after the quads) with a lattice with symmetric FODO cells (sextupoles before and after the quads), and the 2 IR 12-fold layout with the 2 IR baseline layout (less chromaticity than with 4 IRs). In all cases he will use an IR without any local chromaticity correction scheme.

Bernhard mentioned that the symmetric FODO cell and the splitting of the sextupoles were a strong suggestion by colleagues.

Bastian presents the matched W-functions for the non-symmetric FODO cell lattice for one quarter of machine (three arcs and three straight sections), work he already presented at the FCC week in Washington. The W-vector is created by the chromaticity at the final doublet quadrupole and step by step corrected to a small value at the end of the first arc after the IP. It stays flat in the second arc. In the third arc the W vector is step by step recreated to compensate the chromaticity of the second IP's final doublet.

For the symmetric FODO cell lattice, Bastian got problems of convergence while matching the phase advance in the horizontal plane. He introduced a phasor in order to rectify the phase advance between the focusing quad of the final doublet and the first focusing sextupole in the first arc. This phasor is a transfer map increasing the horizontal phase advance by 45 degrees, rotating the W vector by 90 degrees and allowing to reduce the W functions in the horizontal plane with the arc sextupoles. Now he succeeded in the matching of the W function as described above.

Bastian mentioned that the defocusing quadrupole contributes the most to the chromaticity in the vertical plane, whereas it is not so clear for the horizontal one. **Katsunobu** mentioned the contribution also from the straights, which also source of chromaticity, in smaller amount.

The momentum acceptance between symmetric and non-symmetric FODO cell was presented and the difference is not very large (0.16%, 0.14%), therefore up to now the gain is not evident with the symmetric cell. However **Bernhard** mentioned that it might get better with the local chromaticity scheme.

Bastian summarized the results in chromaticity correction for the two FODO cells. **Katsunobu** noticed the contribution of the 4th order in Qy for the symmetric FODO cell.

Frank asked how the matching is done. Bastian replied that he gives as constraints the W function zero at the IP and W< 10 in the arcs. He uses independent sextupoles with 2 families in horizontal and 3 in the vertical plane. The results of the matching strongly depends if Bastian start either in the horizontal plane or the vertical one.

Frank suggested to better correct the linear chromaticity in Hor. for the symmetric FODO cell by introducing more weight on these constraints. **Bernhard** added 3 and 4 order chromaticity in the both planes should better optimized as well, using Anton's formula.

The next steps for Bastian are the following:

- Repeat the study with split quadrupoles (suggested by Katsunobu)
- 60°/60° and 90°/90° phase advance plus non-interleaved sextupole scheme
- Repeat the exercise for the baseline (work in progress). Since the number of IPs is reduced (2 IPs for the baseline), the chromaticity should be reduced. Bernhard estimates that the 3rd order chromaticity should go down by a factor 4.
- Bastian will discuss with the colleagues from BINP about how to combine the local CCS with the arcs.

Bastian raised a problem concerning the PHIX and MUX in Madx. MUX is the conventional phase advance and PHIX is the chromatic phase function being the arctan of the chromatic variable A and B (According to the MADX manual) giving the phase of the W vector. The problem is that the W vector should rotate with twice the phase advance, which the case in the vertical plane, but not in the horizontal one. This problem will be discussed with either **John Jowett or/and Ghislain Roy.**

Bastian is meeting many problems to make the full matching (phase advance, chromaticities, W-functions etc..) and thinks about adding special sextupoles just for the higher order chromaticity correction. Bastian said that he just uses one straight section to match the tune, because the other might be occupied for the injection etc. **Bernhard** said he should use both because he would like to get a lattice design as optimize as possible (This is the goal for September). and make compromises afterwards. This is the goal for September.

Bastian asked how to optimize the interleave sextupole scheme. **Katsunobu** uses the downhill simplex algorithm to optimize energy acceptance and dynamical aperture. He asked whether MADX has higher order W-function implemented. **Helmut** replied by the negative. No design of accelerator was done using higher order W-function.

Frank suggested to use higher order multipoles. **Bernhard** replied he prefers to wait the ongoing studies before including octupoles and decapoles.

Katsunobu Oide: Misc comments.

There will be a mini review of the crab-waist IR option with the BINP colleagues, on Friday the 12 of June. **Michael Benedikt** said that the audience will be restricted, however the slides will be available. An optics meeting will be dedicated to the presentations from the BINP colleagues.

Katsunobu Oide distributed a lattice in MADX. This lattice, the critical energy of the dipoles near the IP (+/- 300 m) is set below 100 keV. thus the beam line is very straight and now very difficult in a single tunnel with 30 mrad crossing angle it the IP. Each beam needs separate tunnel for about 5 km per IP. Michael said that such a second tunnel might be usable for the bypass of the injector synchrotron.

Due to the mini review, the next Optics meeting will take place in two weeks.