Discussion on Recipe for Design of a Compact Final Focus

Andrei Seryi*, Stanford Linear Accelerator Center, Stanford, CA 94309, USA†

Abstract

On the first day of the Nanobeam Workshop [1], several participants commented that they were having difficulties designing a Raimondi-Seryi final focus system with local chromaticity correction [2], and requested a recipe for tuning such a lattice to cancel higher-order aberrations. In response, such a recipe was written and distributed to those interested on the following day. The text of this recipe is reproduced in Sections 1 and 2 with only minor style and language corrections.

1 BACKGROUND

Several participants at Nanobeam reported that they had tried and failed to find a solution for a new final focus with local chromaticity correction. They found the matrix constraints, as published in [2] were insufficient to specify a tuning recipe and asked for more detailed guidance on the steps to follow in refining the FF optics. It is worth pointing out that such a tuning cookbook may create more problems than it solves. Fine tuning of a lattice typically involves a lot of hand optimization, often driven by intuition rather than logic which is not always easy to describe. On the first day of the workshop, the light source participants remarked that optimization of dynamic aperture requires a lot of hand work, confirming this observation. In practice, people typically have to find tuning recipes for themselves.

My own experience when I was trying to design final focus for VLEPP in the beginning of 1989, was that the papers of K. Brown, B. Zotter and O. Napoly were not sufficient to specify the system because of the huge U3466 matrix element. After many attempts and considerable time, I eventually realized that this aberration could be eliminated with a particular solution for the final telescope. So, that was the trick. Only much later I found a paper by K. Oide where he mentioned the importance of the two first "badly placed" quadrupoles in the final telescope, but absence of recipes or automated generators allowed me to develop a much deeper understanding and arrive at the solution independently.

Later, O. Napoly developed the FFADA program to facilitate optimization of the (now) traditional final focus. It automates the generation of different solutions for the final telescope, which was the most tedious part of the work. Nonetheless, minimization of U3466 still required a trick - you would need to request FFADA to find a solution with certain demagnifications Mx and My for the final telescope, then generate the FF, check U3466, change Mx or My,

check U3466, and repeat the entire sequence until the aberration vanished.

For the traditional FF, this trick basically can be expressed as the following recipe: while preserving the main linear and second order constraints, scan possible solutions along a particular degree of freedom (Mx or My in this case), find the optimum, scan along other degrees of freedom (for example play with the ratio of CCX and CCY length), and continue iterating until a proper solution is found or until your intuition tells you that you need to go back and change something, either because you are stuck in a local minimum or because you want too much.

The same approach will work for designing the new final focus. In this case, there are many more free parameters that can be changed, but the basic procedure is the same.

2 A TUNING RECIPE

The following tuning steps can be tried in designing the new final focus, but any recipe should be considered a guide and not a detailed map. It may be necessary to change the strategy or add more steps, depending on the situation (how far you are from a solution) or depending on the tools that you are using. Design of the final focus presented in [2] was done using TRANSPORT. In the following, it is assumed that the basic matching is done with MAD. The element names correspond to the plots shown below.

1) Start from the IP with design values of β^* and η'. Choose reasonable L^*, lengths for the Final Doublet (FD) elements QD0 and QF1 and a separation between them. At a later stage, the lengths and the separation between them can be used as knobs to trade synchrotron radiation (SR) in the FD against FD vibration tolerances.

2) Make a linear match for the optics between SD4 and SF6, imposing proper symmetry in QF7 and $\alpha = 0$ at SD4 and SF6. The distances, or the beta in the waist may be knobs for later optimization.

3) Match QD0 and QF1 to obtain certain values for α_X and α_Y at the exit from QF1 (going away from IP). These values can later be changed to optimize 3rd order aberrations (usually, for the geometric terms).

4) Make a linear match, varying only the strength of QD2A, QF3, QD2B, QD4 and QF5 and imposing simultaneously two constraints:

a) between SD0 and SD4: all Rij=-1 except R12=V_1 and R34=V_2

b) between SF1 and SF6: all Rij=1 except R12=V_3 and R34=V_3 (You may need to play with the distances upstream of the FD if the initial solution is too far off and the matching does not work well. Fine tuning of these distances and

the lengths of the bends give additional knobs). These V_i will be your knobs for further tuning (usually, for chromo-geometric terms).

5) Make a linear match, varying the quads and lengths upstream of QD10 to arrive to a desirable diagonal matrix with certain demagnification for the whole system.

6) Make a linear match, varying the field of B1, B2, B5, requesting zero eta and eta prime at the exit and a certain nonzero value of dispersion at SF5. This value is another knob.

7) Mirror the FF and start from the entrance. Make a second order match requesting zero for T126, T122, T166, T346, and T324 varying the strength of all sextupoles. At a later stage, when the solution is close, one can exclude SF5 or SF6 from the match and leave it for hand tuning. The value will be an additional knob.

8) If you are using MAD, plot the bandwidth. That is about all you can do with MAD, but this is not sufficient. The following may depend on what tools are available. For example, you can save the optics to a survey file and convert this file to a TRANSPORT file using a program available at SLAC from Mark Woodley. For convenience of further evaluation of aberrations, calculate the total matrix of the FF, invert it, and insert this matrix at the beginning of the TRANSPORT beamline, so that the total matrix is equal to unity.

9) Run TRANSPORT and dump out the second and third order matrices, as well as the matrices for the beam with energy offset $+\Delta$ and $-\Delta$. The latter give the higher-order chromatic aberrations.

10) Use the same TRANSPORT beamline and run TUR-TLE for beam tracking. Note that it is important to do tracking and calculate high order matrices by codes that are consistent with each other. TRANSPORT and TUR-TLE are a good combination. Do not try to use matrices from TRANSPORT and tracking by MAD, as tiny differences may mislead you.

11) Remember this state, then return to step 3 and change the value of some knob. Do it for all the knobs. You will soon see, that the knobs affect the third order aberrations. Some affect several aberrations, but differently, allowing eventually all the major terms to be minimized (if a solution in principle exists for the requested parameters).

12) As additional knobs, for example, you can hand tune all distances.

13) Repeat until a solution is found, but do not expect to arrive at it fast. Use appropriate knobs depending on the situation. Certain steps from this procedure can be done automatically using some sort of script. For example, I use some simple programs that generate all the TRANSPORT and TURTLE files and then read and analyze results. But it does not work to just vary all the parameters, without imposing constraints on the linear and second order matrices.

14) When a solution is close, one may try adding an octupole near the FD.

As a practical example, we have developed a preliminary design for a new FF optics for TESLA. The figures below

give the optics as well as a snapshot of the 2nd and 3rd order matrices (absolute values, and in ratio to IP beam parameters) and the tracked luminosity equivalent beam sizes for on energy beam, and also for $-\Delta_E$ and $+\Delta_E$.

One additional remark about the matrix constraints for high order terms given in the paper [2]. These constraints were intended to demonstrate that optimization is possible, and they can be useful to explain why certain parameters have an optimum at a particular value, but optimization can be performed also without using them as actual tuning constraints. It is also interesting to note that the method of tuning presented here (which is based on a procedure, and not on unmeasurable, in a real situation, quantities) can be extended for tuning of a real final focus during commissioning of a linear collider. In fact, design of final focus with this method resembles tuning of a real system.
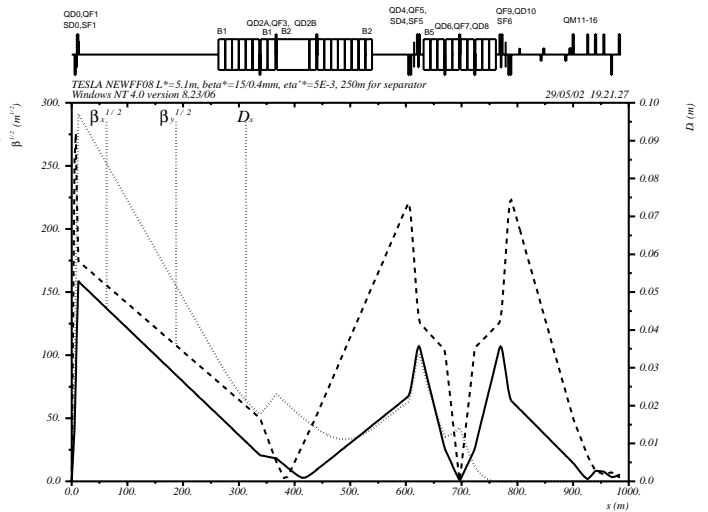

Figure 1: Beta functions of a FF optics design example with $L^* = 5.1$ m and with TESLA IP parameters: $\beta_{x/y} = 15/0.4$ mm. The η' is 0.005.
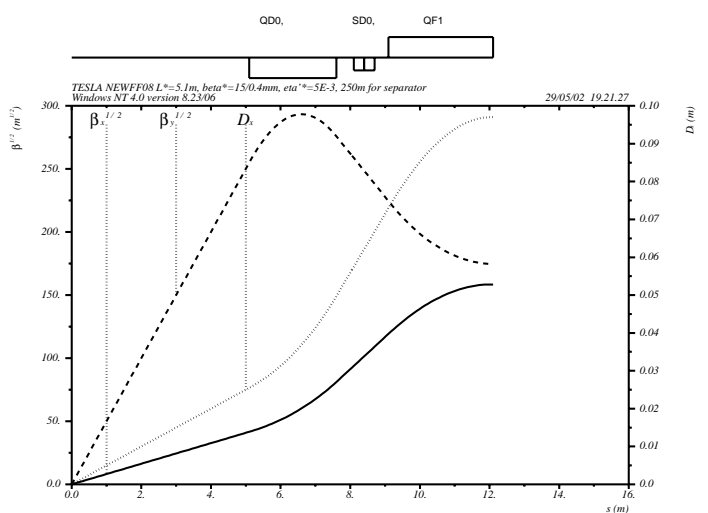

Figure 2: Beta functions of the final doublet region of a FF optics design example with TESLA IP parameters.

Example of an optics produced with this recipe is shown in Fig.1 and 2. This is not a fully optimized optics. With the incoming beam with $\gamma\varepsilon_x/\gamma\varepsilon_y = 10/0.03$ (10^{-6}m) and $\sigma_E = 0.25\%$ the tracked beam sizes are

σ_E	σ_{xp^*}	σ_{yp^*}	σ_x^*	σ_y^*
2.5 pm	38.9 μrad	12.6 μrad	0.632 μm	0.00599 μm

For comparison, the nominal IP beam parameters are

σ_{xp^*}	σ_{yp^*}	σ_x^*	σ_y^*
36.8 μrad	12.5 μrad	0.553 μm	0.005 μm

The tables below show the largest remaining second and third order terms for the on energy beam and for the beam which is offset in energy by $\Delta_E = \pm 0.1\%$. The actual values of the matrices, as well as normalized values (with respect to the nominal beam sizes at the IP) are given.

On energy beam

indexes	T_{ijk}	T relative
1 1 2	-0.31070E-03	0.0114
1 6 6	0.39550E-02	0.0447
3 1 4	-0.32000E-04	0.0442
3 2 3	0.10150E-02	0.0374
4 2 4	-0.10140E-02	0.0373
	U_{ijkl}	U relative
1 1 2 6	-0.13110E-03	0.0121
1 2 2 2	-0.32280E-06	0.0291
1 2 2 6	-0.19010E-04	0.1164
1 2 6 6	-0.44920E-04	0.0187
3 1 4 6	-0.34790E-05	0.0120
3 2 2 4	0.13880E-07	0.0470
3 2 4 6	0.18530E-05	0.4262
3 4 6 6	0.75640E-06	0.0118

$\Delta_E =$**-0.1%**

indexes	T_{ijk}	T relative
1 2 2	0.23050E-04	0.0564
1 2 6	0.84440E-04	0.0140
1 6 6	0.40320E-02	0.0456
3 1 4	-0.28270E-04	0.0391
3 2 3	0.10690E-02	0.0393
3 2 4	-0.21400E-05	0.1969
3 4 6	-0.34310E-05	0.0214
4 2 4	-0.10640E-02	0.0392
	U_{ijkl}	U relative
1 1 2 6	-0.12110E-03	0.0111
1 2 2 2	0.75400E-06	0.0680
1 2 2 6	-0.27120E-04	0.1660
1 2 6 6	-0.39380E-04	0.0164
3 1 4 6	-0.39970E-05	0.0138
3 2 2 4	0.92190E-07	0.3121
3 2 4 6	0.24240E-05	0.5575
3 4 6 6	0.26800E-05	0.0419

$\Delta_E =$**+0.1%**

indexes	T_{ijk}	T relative
1 1 2	-0.44510E-03	0.0164
1 2 2	-0.15010E-04	0.0368
1 2 6	-0.95170E-04	0.0158
1 6 6	0.38120E-02	0.0431
3 1 4	-0.35280E-04	0.0488
3 2 3	0.96860E-03	0.0356
3 2 4	0.15670E-05	0.1442
4 2 4	-0.96500E-03	0.0355
	U_{ijkl}	U relative
1 1 2 6	-0.13700E-03	0.0126
1 2 2 2	-0.13870E-05	0.1250
1 2 2 6	-0.11020E-04	0.0675
1 2 6 6	-0.50300E-04	0.0209
3 1 4 6	-0.31140E-05	0.0108
3 2 2 4	-0.63360E-07	0.2145
3 2 4 6	0.12830E-05	0.2951
3 4 6 6	-0.11690E-05	0.0183

Observation of such matrices helps to create knobs for tuning. Matrices for off energy beam and also their asymmetry (for $+\Delta_E$ and $-\Delta_E$) give information about higher order chromatic aberrations.

3 CONCLUSION

A recipe for compact final focus design and an example of its use is presented for discussion. With some modifications, the recipe can be extended for tuning of a real final focus during commissioning of a linear collider.

4 REFERENCES

[1] 26th Advanced ICFA Beam Dynamics Workshop on Nanometre-Size Colliding Beams, September 2-6, 2002, Lausanne, http://icfa-nanobeam.web.cern.ch/

[2] P. Raimondi and A. Seryi, "A Novel Final Focus Design for Future Linear Colliders," Phys. Rev. Lett. **86**, 3779 (2001).