Matching Solutions for Various Wiggler Operating Configurations

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Abstract

Quadrupole telescope matching solutions are given for eight wiggler operational scenarios that are specified by various combinations of the following parameters.

- Beam kinetic energy: 38 or 42 MeV
- $k^2_{wiggler}$: ½ or 0.96
- Machine operational mode: straight-ahead or energy recovering

A new EXCEL-based machine model was used to generate these solutions. It is briefly described.

Introduction

Wiggler operation at multiple energies and k^2 values imposes a variety of matching conditions on the quadrupole telescopes upstream and downstream of the wiggler insertion. These matching conditions also differ based on the operating mode of the driver accelerator (straight-ahead or energy recovering). This note details electron beam optical solutions for various cases of this matching problem. The following features are to be noted.

- For the Jefferson Lab IR FEL, the wiggler bends vertically and focuses horizontally.
- The desired target horizontal beam envelope is the "matched beta" for the wiggler. This "matched" beam envelope is the periodic Twiss function for motion in the non-bending plane of a symmetric chicane of parallel faced dipoles, which are excited at the rms field value of the wiggler and have a total length equal to the wiggler period. The value of the matched beta is completely defined by the wiggler period, $k^2_{wiggler}$ and the electron beam energy. In our parameter regime it is to high precision the bend radius of the electron beam as it moves through a field equal in magnitude to the rms wiggler field. The desired slope of the matched beam envelope (α) is, by the symmetry of the chicane model, simply zero.
- The desired target vertical beam envelope at the wiggler center is (for JLab IR FEL parameters) β_y=0.5 m with α_y=0.

- Matching targets at the wiggler are achieved by adjustment of the quadrupole telescope upstream of the wiggler. Matching targets downstream (either matching to the recirculator acceptance, for energy recovery, or matching to an appropriate spot at the straight-ahead dump) are met by adjusting the telescope after the wiggler, assuming the upstream match into the wiggler has been implemented.
- Initial conditions for the matching are taken to be the design beam envelope function values immediately downstream of the cryomodule. These are radially symmetric, with $\beta_{x,y}$ = 7.233 m and $\alpha_{x,y}$ = –0.4987. Design values are used for all magnet parameters as well; for example, we take K_1=0.27 for all dipoles. During machine operations, these will be updated to reflect as-built and observed values. Thus, observed beam envelopes will be used to provide initial conditions for matching and measured magnet parameters (such as K_1~0.317 [1] for transport system dipoles) will be used where appropriate.

Model

Matching computations were done using a new EXCEL-based model. This tool will be describe in some detail elsewhere [2]. For the purpose of this note, we simply list some of the salient features.

- Detailed element descriptions are included.
- Individual 6x6 linear element transfer matrices (from TRANSPORT [3]) are computed.
- A running product of 6x6 transfer matrices is evaluated.
- Tables and graphical presentations of propagated beam envelope functions, dispersions, and phase advances are provided.
- Linear (and, in principle, thin-lens nonlinear) ray tracing is available, as are tabular and graphical presentations of the orbits.
- Using the EXCEL Solver feature, various optimizations can be performed. These include
    - fitting of element, beam line matrix, and transported beam parameters (matrix elements, beam envelopes, dispersions, and phase advances) at any point, using any parameter,
    - emittance data reduction and phase space characterization,
    - orbit analysis and correction, and
    - fitting of observed orbit data to conjectured beamline error sources.
- Though not presently enabled, in principle the following features can be readily implemented:
    - network communication using ActiveX protocols,
    - performance enhancement through use of Visual Basic and EXCEL array-handling tools,
    - fitting of beamline layouts,
    - nonlinear element transformations, and

- o event-driven control and event binding, to allow "video-game standard" interactive control of the computation flow.

The model is fully interactive and completely transportable to any EXCEL-capable platform. The interface is intuitive; it uses standard EXCEL objects, tools, and methods. It is therefore immediately accessible to any user familiar with spreadsheet methods. Additions and upgrades to the model are generally easily accomplished. The model concept is object-oriented (Microsoft EXCEL being what it is!), yet all data and underlying relations are public, so neither is data is reserved nor are features hidden; *what you see is what you get!*

Sample FEL models can be obtained from the author by request.

Solution Values

Quad Excitations for Matching to Energy Recovery Transport – Table 1 provides quadrupole settings for 38 and 42 MeV beam energies with wiggler $k^2_{wiggler}$ values of ½ and 0.96 that match design beam envelopes from cryomodule exit to energy recovery design betatron acceptance values. Figure 1 presents a sample plot of the beam envelopes/dispersions through this region for the case of 42 MeV beam and $k^2_{wiggler}$ =1/2.

Quad Excitations for Matching to Straight-Ahead Dump – Table 1 provides quadrupole settings for 38 and 42 MeV beam energies with wiggler $k^2_{wiggler}$ values of ½ and 0.96 that match design beam envelopes from cryomodule exit to a round spot with $\beta_{x,y}$ = 30 m and $\alpha_{x,y}$ = –3 at the straight ahead dump. Figure 2 presents a sample plot of the beam envelopes/dispersions through this region for the case of 42 MeV beam and $k^2_{wiggler}$ =1/2.

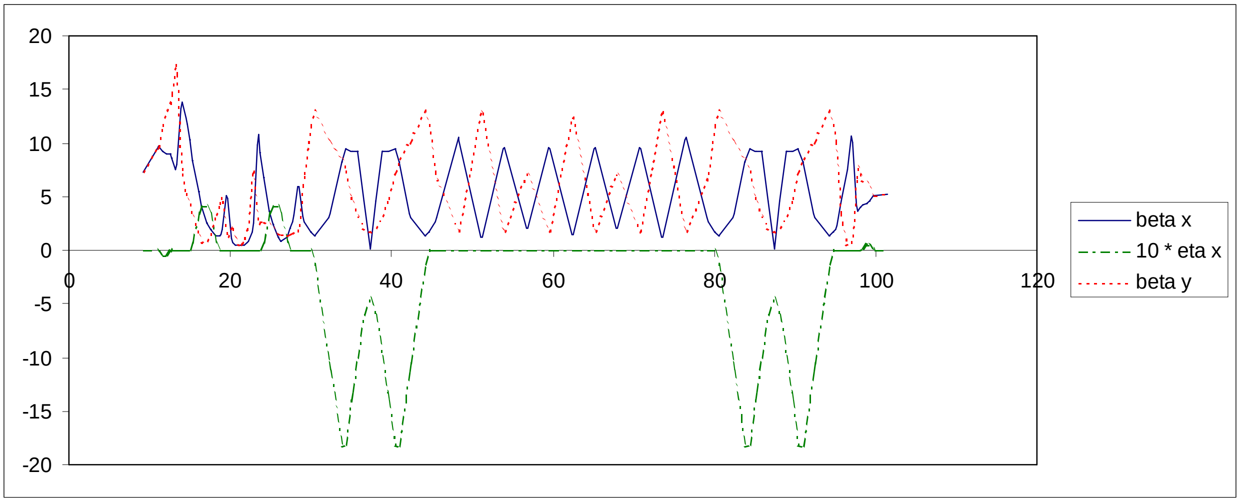

Figure 1: Beam envelopes/dispersion through recirculator for 42 MeV beam when $k^2_{wiggler}$ =1/2.

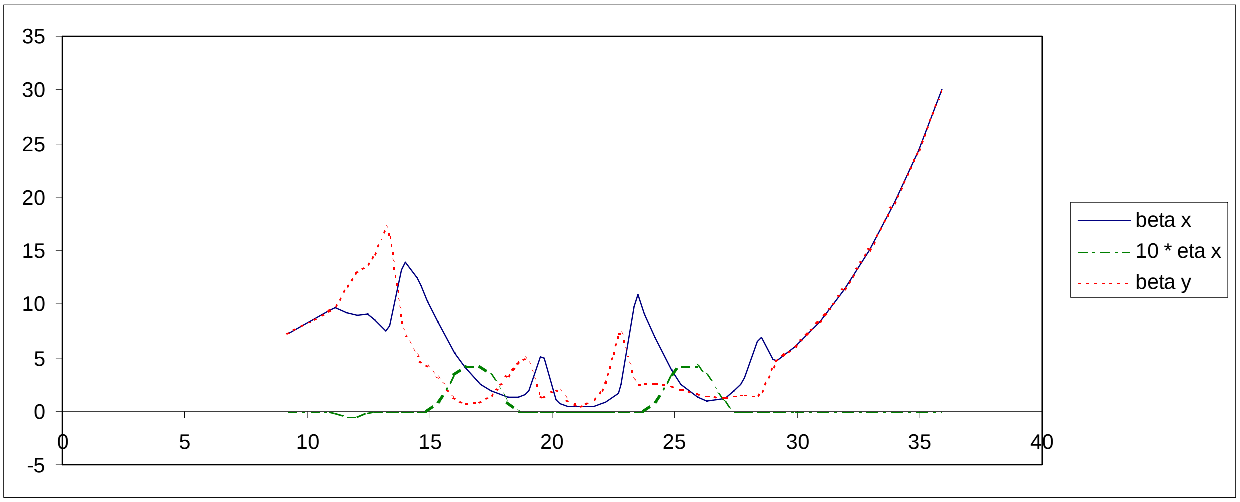

Figure 2: Beam envelopes/dispersion to straight-ahead dump for 42 MeV beam when $k^2_{wiggler}$ =1/2.

Table 1: Matching Quadrupole Excitations for Various Wiggler and Driver Operating Modes

	Kinetic Energy (MeV)							
	38				42			
	$k^2_{wiggler}$							
	0.5		0.96		0.5		0.96	
matched β_x at wiggler	0.457998 m		0.330532 m		0.505569 m		0.364863 m	
matched β_y at wiggler	0.5 m							
	Operating Mode: Straight Ahead (SA) or Energy Recovering (ER)							
	SA	ER	SA	ER	SA	ER	SA	ER
	quad B'/Br (1/m^2)							
QG1F03	-4.77748		-5.03014		-4.78097		-5.00743	
QG1F04	3.65835		4.01701		3.65300		3.93641	
QG1F05	0.85250		0.74128		0.82855		0.78553	
QB2F01	-6.97547		-6.60666		-6.89470		-6.58497	
QB2F02	12.40732		12.78630		12.20085		12.67079	
QB2F03	-9.39675		-9.40675		-9.29035		-9.36823	
QB2F04	3.5	3.5	5	5	3.5	3.5	5	5
QB2F05	-10	-10	-10	-10	-10	-10	-10	-10
QB2F06	8.452428	8.490157	8.377779	8.407688	8.436433	8.481003	8.372802	8.409112
QB2F07	-2.715739	-1.252815	-5.49027	-3.258929	-2.636577	-1.176457	-5.398155	-3.169612
QB2F08	6.429815	7.190687	8.058092	8.452653	6.276483	7.034973	7.925761	8.305996
QB2F09	-3.608454	-2.607322	-4.537659	-3.226458	-3.557027	-2.567712	-4.499523	-3.196383

Acknowledgments

I would like to thank Steve Benson for instructing me about wiggler operating and matching conditions and motivating me to get this calculation done.

Notes and References

[1] J. Karn, unpublished.

[2] D. Douglas, "Alternate Paradigms for High-Level Applications", JLAB-TN in preparation.

[3] K. Brown *et al.*, "TRANSPORT A Computer Program for Designing Charged Particle Beam Transport Systems", SLAC-91 Rev. 2, UC-28 (I/A), May 1977.