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VICKY: A COMPUTER CODE FOR USE IN THE DESIGN AND SIMULATION OF PARTICLE ACCELERATORS

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Abstract

Vicky is a computer code under development for designing and simulating particle accelerators. Like other existing codes, the features include machine imperfections, closed orbit correction, Twiss functions matching, chromaticity evaluation and correction, particle tracking and so on. The goal is to give the users a friendly graphical interface with widgets to perform the wished tasks, for example to plot the orbit, the Twiss functions, the tune diagram, the dynamic aperture and so on, to select and read an input file describing the considered lattice, to perform the Twiss functions matching, a closed orbit correction and so on. The code provides a description of the particle motion by 10 parameters: four beta-functions, four alpha-functions and two phase advances, meaning a 4*4 generalized transverse coupling, together with an emphasis on the treatment of the complex 3D magnetic fields of the undulators used in today's modern synchrotron radiation facilities. The code is written in C++. It uses the free packages QT for the online plots and the graphical user interface and IT++ for the mathematics. The present status and some results of its application will be presented.

INTRODUCTION

The code Vicky provides three main features: a simple free format input file to describe the lattice, simple widget tools to perform different calculations, like the Twiss functions matching, the closed orbit correction, the phase space and dynamic aperture tracking, and finally the plot of the closed orbit, before and after correction, the obtained correctors kick values, the dynamic aperture, the phase space, the Twiss functions, etc. The magnets considered up to now are bendings, correctors, kickers (with possible varying kick strength), quadrupoles, sextupoles and undulators. Its main panel is shown in figure 1.

File	Display	Plot	Matching	Selection	Orbit correction	Store for plot	Tracking
QMF	drift	876	254.7050	0.1260	16.051	-12.713	14.227
Q2	quadrupole	877	255.2030	0.4080	19.187	7.629	14.231
Q02	drift	878	255.5440	0.3410	14.343	6.577	14.234
S1	sextupole	879	255.5440	0.0000	14.343	6.577	14.234
Q01	drift	880	255.6240	0.2800	10.902	5.713	14.238
Q1	quadrupole	881	256.0840	0.2600	9.384	0.380	14.242
Q002	drift	882	256.2040	0.1200	9.294	0.305	14.244
Q00	bpm	883	256.2040	0.0000	9.294	0.305	14.244
Q001	drift	884	256.6740	0.4700	8.978	0.308	14.252
Q00	corh	885	256.6740	0.0000	8.978	0.308	14.252
Q00	corv	886	256.6740	0.0000	8.978	0.308	14.252
Q055	drift	887	259.2000	2.5260	8.199	0.000	14.300

name	type	number	tleng	sleng	betall	alpha1	mu1/2pi
			n	n			
d1_entrance	=	7.902654579e-05			d1_entrance'	=	1.034638015e-16
d1_exit	=	7.902654579e-05			d1_exit'	=	-2.549070216e-16
d2_entrance	=	0.000000000e+00			d2_entrance'	=	0.000000000e+00
d2_exit	=	0.000000000e+00			d2_exit'	=	0.000000000e+00
cod1_entrance	=	0.000000000e+00			cod1_entrance'	=	0.000000000e+00
cod1_exit	=	0.000000000e+00			cod1_exit'	=	0.000000000e+00
beta11_entrance	=	8.199365964e+00			alpha11_entrance	=	-4.494326650e-15
beta11_exit	=	8.199365964e+00			alpha11_exit	=	1.490994828e-15
beta12_entrance	=	0.000000000e+00			alpha12_entrance	=	-0.000000000e+00
beta12_exit	=	0.000000000e+00			alpha12_exit	=	-0.000000000e+00
beta22_entrance	=	2.560977137e+00			beta22_entrance'	=	2.560977137e+00
beta22_exit	=	2.560977137e+00			beta22_exit'	=	2.560977137e+00
beta21_entrance	=	0.000000000e+00			beta21_entrance'	=	0.000000000e+00
beta21_exit	=	0.000000000e+00			beta21_exit'	=	0.000000000e+00

Total length	=	259.200000000 m			mu1/2pi	=	14.300000000
delta_s	=	-0.000000000 mm			xi1	=	0.0573096168
Alpha_c	=	1.599557e-03			mu2/2pi	=	8.200000000
					xi2	=	0.000466126

Figure 1: Vicky main panel with displayed optics.

INPUT FILE

The physical elements and markers are defined by statements in a form somewhat similar to the one used in madx. Example:

```
ooo: drift, l = 2.526; → drift
qf: quadrupole, l = 0.409, k1 = -2.2258; → foc. Quad.
qd: quadrupole, l = 0.26, k1 = 1.4; → defoc. Quad.
b: rbend, l = 1.4489, angle = 15, n = 13.072; →
rectangular bending magnet or
b: sbend, l = 1.4489, angle = 15, n = 13.072, e1 = 7.5, e2 = 7.5;
→ sector bending magnet with entrance and exit angles.
coh: corh, k0l = 0; → horizontal corrector
cov: corv, k0l = 0; → vertical corrector
sf: sextupole, k2l = -4.22; → foc. sextupole
sd: sextupole, k2l = 3.7; → defoc. sextupole
ki: kicker, k0l = 15.15e-3, fall_time = 3e-3; → kicker
mon: bpm; → bpms for orbit position
flsc: monitor; → fluorescent screen
mm: marker;
```

The differences with madx are:

- The signs of k0l, k1 and k2l are negative when in madx they are positive and vice versa
- For the bendings, one can give either k1 either the index. Furthermore, the angles are introduced in deg and not in rad.
- For the kickers used for injection, for example, one can give the falling time of the kick (in second), useful for the phase space tracking of injected particles

For the undulators, we can either use a kick map, in this case, we write in the kick map file, example:

```
id_c:ID,file=/fermi/tab_fell_c80_0.9gev.dat;
```

or define the undulator parameters, example:

```
id_c:ID,pl=0.055,np=42,perslices=10,bx0=0.62,
```

by0=0.62,kxp=-169,hx=64; where pl is the period length, np is the number of periods, perslices is the number of integration steps per period, bx0 and by0 are the horizontal and vertical peak fields (in Tesla), respectively.

The lengths and period lengths are in meter. K0l are in rad. K1 and k2L are in m⁻².

The lattice is defined as in madx. For example:

```
cell: line=(id_c,d11,qd,d12,id_c,d11,qf,d12,id_c);
```

```
lat: line= ( 3 * (cell));
```

The particle energy (in GeV) and emittances (in m.rad) are given in:

```
Beam,energy=0.9,emittance_h=5e-6,emittance_v=2e-6;
```

If the emittances are not given they are set to 1 mm.mrad by the program. If they are normalized emittances, then add 'flag_emit_n' in the above line. The lattice to use is indicated in the "use" command. For example:

```
Use, lat;
```

CLOSED ORBIT AND TRAJECTORY

In the code Vicky, the misalignments can be assigned in two ways. Using the name of the physical element:

- **Ealign,name=B,dx=0.3e-3+0.2e-3*gauss();**

Or the type of element:

- **Ealign,type=quadrupoles,dx=0.15e-3*gauss();**

In the 1st case, all the elements with name B will be assigned the misalignments of the elements B). In the 2nd case, all the quadrupoles will be assigned the misalignments listed in the quadrupoles type).

Dx,dy and ds are the position errors in meter along the horizontal, vertical and longitudinal axes, respectively. rotx, roty and rots are the rotation errors in rad around the horizontal, vertical and longitudinal axes, respectively. The number before *gauss() is the rms error. The number without *gauss() or before the + is the systematic error if any. One can also give the cut off inside the parenthesis of gauss, example a cut off at 2.5 sigma, will be gauss(2.5). The user can ask the program to perform statistics and with a seed starting number, if wished. For example, 20 statistics and starting seed 33456900:

Error_option, seed=33456900,nstatistics=20;

For the methods svd and micado, respectively, the correction commands are simply:

Correct,method=svd,plane=both,eigenh=20,eigenv=20, iterations=2;

Correct,method=micado,plane=both,ncorh=2,ncorv=2, iterations=1;

The plane can be “both”, “horizontal” or “vertical”. Iterations are the number of iterations. For svd method, the user provides the number of eigen values for the horizontal “eigenh” and vertical plane “eigenv”, respectively. For micado method, the user provides the number of most effective correctors, for the horizontal “ncorh” and vertical plane “ncorv”, respectively. Figure 2 shows the panel for the orbit and trajectory correction.

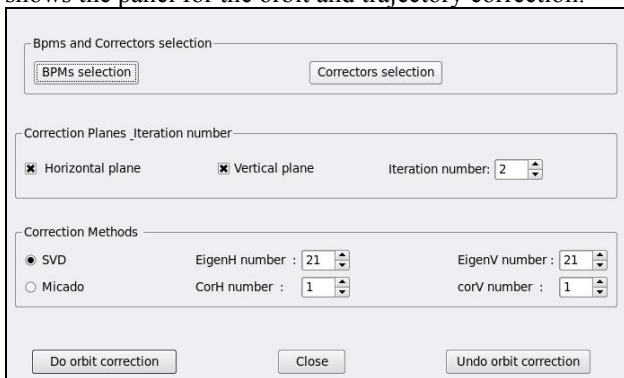


Figure 2: Orbit and trajectory correction panel.

The BPMs and correctors can be disabled or enabled via the widgets “BPMs selection” and “Correctors selection”, respectively. Furthermore the BPMs can be given a weight. Via the widget “Plot orbit” of the main panel menu “Plot”, the user can plot the orbit before and after correction, all together, before and after separately, horizontal and vertical separately, etc. Figure 3 shows 20

statistics of the orbit before and after correction, both planes, all together, in an Elettra ring example.

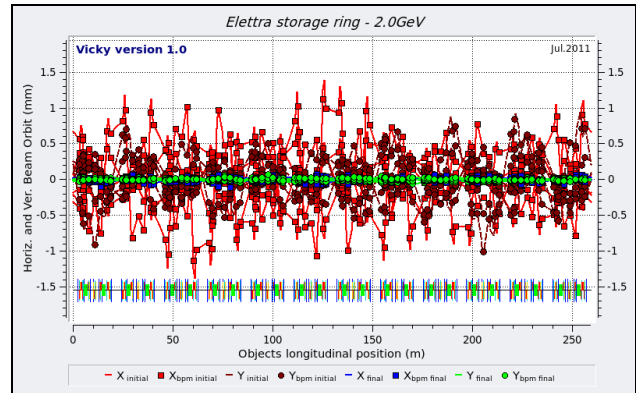


Figure 3: Orbit before and after correction in Elettra ring.

Via widget “Plot correctors” of the main panel menu “Plot”, the user can plot the obtained kick values of the correctors, as shown in figure 4.

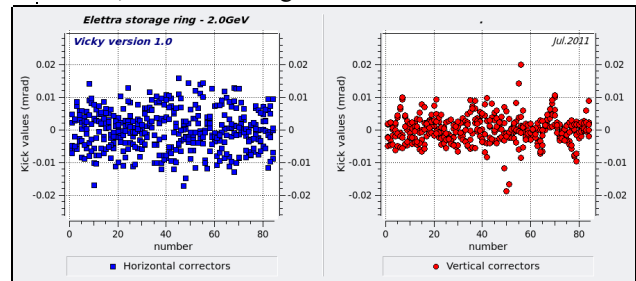


Figure 4: Correctors kicks values obtained for orbit correction in Elettra ring.

TWISS FUNCTIONS MATCHING

In the code Vicky, the Twiss and dispersion functions together with chromaticity matching is obtained via svd method. The requests can be introduced in the input file like in madx or directly set and also changed as wished in the matching panel shown in figure 5.



Figure 5: Matching panel.

The commands are simply:

Match, niterations=5;

Constraint, qh=14.3, qv=8.2,xix=0,xiy=0;

Vary, name=q2, step=1e-5,min=-3,max=0

Vary, name=sf, step=1e-5,min=-6,max=2;

Endmatch;

The user can specify the weights and the tolerances, adding the following lines before endmatch:

Weight, $qh=1000$, $qv=1000$, $xix=100$, $xiy=100$;

Tolerances, $qh=1e-6$, $qv=1e-6$, $xix=1e-2$, $xiy=1e-2$;

These values can be set or changed in the matching panel widgets “Constraints: weights” and “Constraints: tolerances”, respectively.

PHASE SPACE TRACKING

Vicky provides the phase space tracking and plot. The tracking command is simply:

Tracking,option=phasespace, $nrev=50$, $np=10$, $npsi=2$;

Where $nrev$ is the number of turns, np is the number of particles per plane and $npsi$ is the number of combinations, meaning the total number of particles is $npsi*np*np$. The amplitude limits above which the particle is lost, or above which the amplitudes diverge are given in meter in the command:

amplitudeLimits, $apx=30e-3$, $apy=30e-3$;

To follow the particles from the exit of an injection septum and then through injection kickers, the user has to give the initial twiss functions with the command:

Twiss, $betah=8.2$, $betav=2.6$, $alphah=0$, $alphav=0$;

and the central position of the particles distribution:

Tracking,option=phasespace, $nrev=50$, $np=10$, $npsi=2$,
 $xc=-29e-3$, $xcp=0$, $yc=0$, $ycp=0$;

For the injection kickers, the user provides $k0l = 90\%$ of their peak values together with the falling time. One can also see the position of the septum sheet in the plot, simply adding the command:

Septum sheet, $xs=-20e-3$, $w=2.5e-3$, $hm=-10e-3$, $hp=10e-3$;
where xs is the position of the septum sheet with respect to the ring or booster axis, w its width, hm and hp are the vertical scale of the phase space plot. Figure 6 shows the phase space for the Elettra ring (revolution period $0.86\mu s$, kicker falling time $3\mu s$) when the chromaticity sextupoles are set to zeroing the chromaticities and the harmonic sextupole is optimized for a good dynamic aperture.

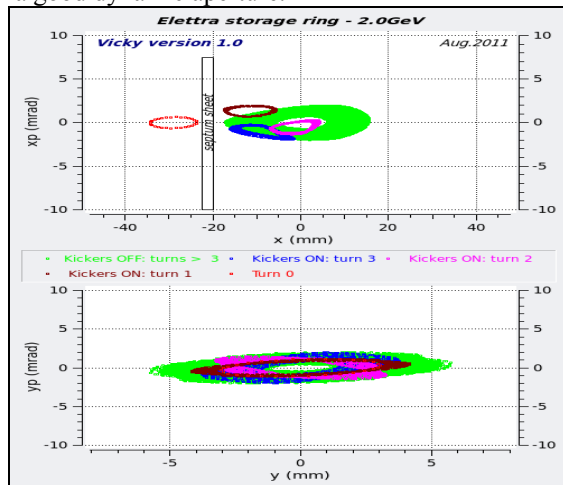


Figure 6: Example of phase space tracking for Elettra ring.

DYNAMIC APERTURE TRACKING

The tracking command is simply:

Tracking,option=dynamicaperture,

$nrev=50$, $np=10$, $npsi=2$, $amph=0$, $ndamph=20$,

$damph=2e-3$, $ampv=0$, $ndampv=60$, $dampv=5e-3$;

Where $nrev$, np and $npsi$ are as defined in the phase space tracking section. $Amph$ and $ampv$ are the starting amplitudes. $damph$ and $dampv$ are the amplitude steps. $Ndamph$ and $ndampv$ are the number of steps. H and V refer to horizontal and vertical plane, respectively. The amplitude limits above which the particle is lost, or above which the amplitudes diverge are also defined as in the phase space tracking section. One can also draw the physical vacuum chamber, adding the command:

vacuumAperture, $name=aper$, $aph=20e-3$, $apv=13e-3$;

where $aper$ is a marker put in the lattice as first element, aph and apv are the half physical apertures of the vacuum chamber in horizontal and vertical plane, respectively. Figure 7 shows the dynamic aperture for the Elettra booster when the chromatic sextupoles are set to zeroing the booster chromaticities.

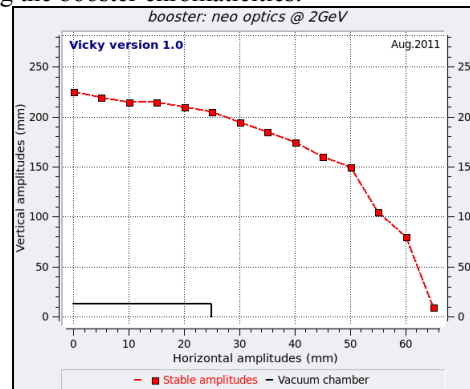


Figure 7: Dynamic aperture example for the Elettra booster.

REMARKS

For lack of space, the complete list of tools provided by Vicky and full details are not reported. A user guide will be soon available [1]. Furthermore, the theory behind the code will be published in a separate paper [2]. For the undulator's treatment, a little can be found in [3,4].

REFERENCES

- [1] F. Iazzourene, “Vicky User Guide”. To be published
- [2] F. Iazzourene, “Vicky Physics”. To be published
- [3] F. Iazzourene, “Linear Electron Transverse Optics along FEL-1”, Internal report, Trieste, Italy
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