CODE COMPARISON FOR ACCELERATOR DESIGN AND ANALYSIS*

Zohreh Parsa
Brookhaven National Laboratory
Upton, NY 11973, USA

Abstract

We present a comparison between results obtained from standard accelerator physics codes used for the design and analysis of synchrotrons and storage rings, with programs SYNCH,[1] MAD,[2] HARMON,[3] PATRICIA,[4] PATPET,[4] BETA[5], DIMAD[6], MARYLIE[7] and RACETRACK[8]. In our analysis we have considered 5 (various size) lattices with large and small bend angles including AGS Booster (10° bend), RHIC (2.24°), SXLS, XLS (XUV ring with 45° bend) and X-RAY rings.[9] The differences in the integration methods used and the treatment of the fringe fields in these codes could lead to different results. The inclusion of nonlinear (e.g. dipole) terms may be necessary in these calculations specially for a small ring.

I. Introduction

Selection of a beam optics code for the design of an accelerator is not only important but could be detrimental to the design if an incorrect code is used. In order to correct and/or control the parameters of a given machine, for example the chromaticity of a synchrotron, we first need to calculate (analytically and/or with one of the available accelerator codes) the natural (uncorrected) chromaticity of that machine; (the incorrect values of chromaticity used in determining the strengths of the correcting sextupoles could lead to problems)[10]. Due to space limitation we will present a sample of the results obtained, showing the dependence and variations of tune and chromaticity with respect to the changes in momentum for the lattices we have considered with different codes (see Tables I-IV for lattice parameters). In this presentation, the number of decimal places shown is (arbitrary) given for theoretical comparison of data. Figures 1-5 shows the lattice functions for the Booster, RHIC, SXLS, XLS and the X-RAY rings respectively.

II. Lattice Parameters

Following tables provide brief summaries of the parameters (describing the lattices) used in our analysis and discussions given in the next section.

Table I. AGS Booster Parameters[11]

ENERGY (Injec/Ejec)	200 MeV/1.5 GeV
No. of Particles/Pulse	1.5×10^{13}
Circumference	201.78 m (1/4 AGS)
Magnetic bend radius ρ	13.75099 m
Periodicity	6
No. of cells/Cell Length	24 FODO/8.4075 m
Phase advance/cell	72.3°/72.45°
ν_x/ν_y (nominal tunes)	4.82/4.83
β_y max/min, X_p max	13.6/3.7 m/2.95 m
transition γ	4.881
DIPOLES (No./Mag.Length)	36/2.4 m
Gap/Vac.Chamber Aperture	82.55 mm/66 mm
Good field region ($<10^{-4}$)	16x6.6 cm
Injec/Ejec field (kG)	1.56/5.46
QUADRUPOLES (No./Mag.Length)	48/50.375 cm
Aper./Vacuum Chamber Apert.	16.5 cm/15.25 cm
Injec/Ejec pole tip field (kG)	1.02/3.6
CHROMATICITY SEXTUPOLES	
Number (being reviewed)/length	2x12/10 cm
Max. pole tip field (kG)	2.0
Max. Vacuum Pressure	3×10^{-11} torr

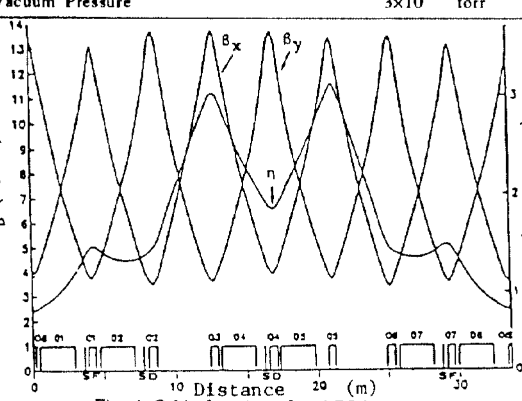

Fig. 1 Orbit functions for AGS-booster.

Table II. RHIC Parameters

LATTICE - Heavy Ion Collider (for P to Au)		
Circumference (m)	3833.87	
Magnetic rigidity (T/m)	96.5 @inj 839.6 @max	
Radius of arcs (ave.)	381.23 m	
Dipole bending radius	243.241 m	
Beam separation in arcs	90 cm	
Periodicity -	6	
No. of cells/arc, length	12 FODO/29.62 m/cell	
Phase advance/cell	90 deg.	
ν_x/ν_y (nominal)	28.826/28.822	
Beta (in arc) max/min	50.1 m/8.5 m	
Dispersion (in arc) max/min	1.52 m/0.74 m	
Transition gamma	25.	
Beta (in insertions) max -	400 m	
Beta/Dispersion (at crossing)	3 m/0 m	
Coll. Angle	6 mrad (head on)	
PERFORMANCE	Proton	Gold
Energy(range/beam)	28.5-250GeV	7-100GeV/amu
No. of particles/bunch	1.0E+11	1.0E+09
Norm. emittance (pi-mm-mrad)	20	10 @ start
(95% of beam)		30 after 10 hrs.
Initial luminosity ($/cm^2/s$)	9.5E+30	9.2E+26 (head on)
Luminosity lifetime	10 hrs	
Longitudinal Bunch Area (95%)		
injected for Gold		0.3 eV-sec/amu
above transition for	1eV-sec/amu	1 eV-sec/amu
Bunch length (rms)	31 cm	50 cm
No. of Bunches/Beam	57	
Bunch separation (224 nsec or)	67 m	
Beam-Beam Tune Shift (initial)	3.7E-03	2.5E-03
MAGNETS		
Superconducting	single layer, 1 in 1 (cold iron)	
Dipoles No.	372 (180/ring+12 common)	
Field (@100 GeV/amu)	3.448 T (dipole mag. L=9.45m)	
Current(@100GeV/amu)	4.56 kA (dipole yoke L=9.7m)	
Quadrupoles No.	492 (276 arc + 216 insertion)	
Gradient	67.4 T/m (quad. mag. L=1.24 m)	
Diamond length	±27 (@100 GeV/amu, 2mrad)	

Table III. SXLS Parameters

Circumference/ρ (m)	8/0.5683
Nominal tune (ν_x,ν_y)	1.415, 0.385
ε,α	0.758/0.330053
max (β_x,β_y)	2.35019, 6.43594
max (η_x,η_y)/γ_{tr}	1.213432, 0/1.74064
Dipoles	
Number (type)	2 (sector)
Length (m)/Angle	0.4463679/45°
Quadrupoles	
Length/Strength	0.197/2.48

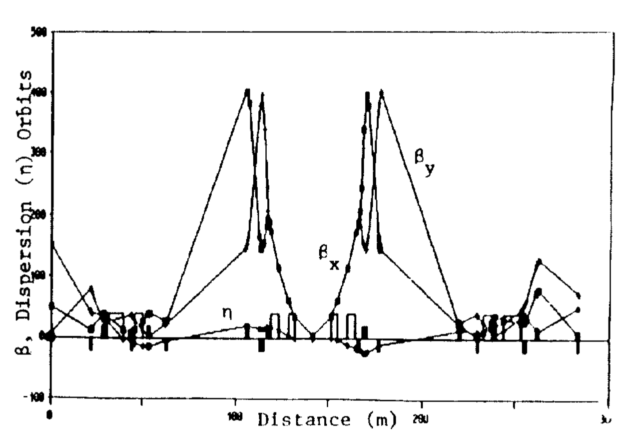

Fig. 2 RHIC insertion orbit function.

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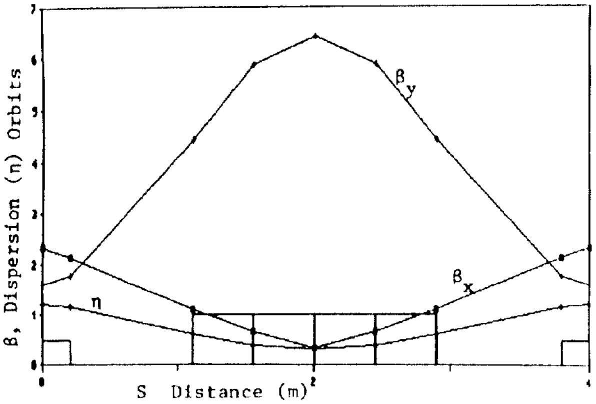

Fig. 3 SXLS orbit functions.

Table IV. XLS and X-RAY Parameters

	XLS	X-RAY
Cir./ρ (m)	38.537/2.25	170.08/6.875
ν_x,ν_y	3.14, 1.18	9.144/6.202
ε/α	0.193/0.0363687	0.102/0.0065419
transition γ	5.229320	12.36365
max (β_x,β_y)	10.880712/13.850470	19.72089/21.90339
max (η_x,η_y)	1.29341/0	1.42062/0
Dipoles		
Number (type)	8 (parallel)	16 (parallel)
Length (m)/Angle	1.767145860.785398	2.7/0.39269908
Quadrupoles	Length/Strength	Length/Strength
q^1	0.25/3.02486961	0.45/-1.50186576
q^2	0.25/-2.53032937	0.8/1.33731236
q^3	0.17/3.83818513	0.4132-1.4018946
q^4		0.225/1.29943942

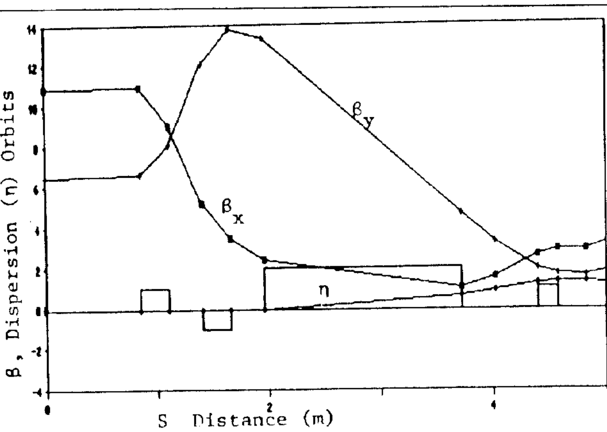

Fig. 4 XLS orbit functions.

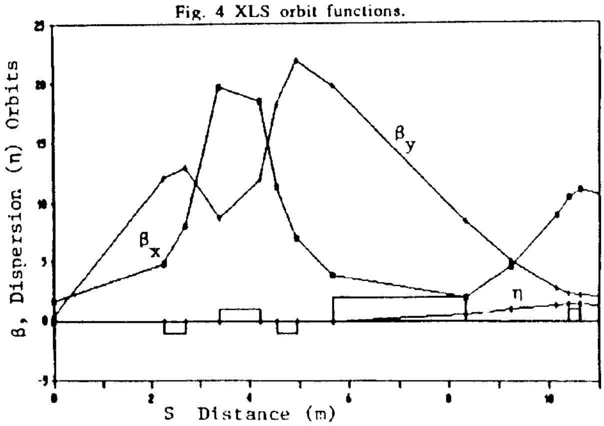

Fig. 5 X-ray orbit functions.

III. Chromaticity Calculations and Comparisons

In Tables V-X we have summarized the results of the chromaticity calculations for the lattices described above in Tables I-IV, with programs SYNCH88[1], MAD6[2], HARMON[3], PATRICIA88[4], PATPET[5], DIMAD[6], BETA[7], MARYLIE[7] and RACETRACK[8].

Table V. Natural Chromaticity C_x,C_y Calculated for the AGS Booster

	AGS-Booster – Natural Chromaticity	
Program	C_x	C_y
SYNCH	-4.92970	-5.26488
MAD6	-4.929702	-5.264883
HARMON (Hchrom)	-5.36876	-5.44737
HARMON (Hfunc)	-5.09315	-5.44730
PATRICIA88.4	-4.92970	-5.26488
PATPET88.2	-4.92970	-5.26488
MARYLIE	-4.92970185	-5.26488371
Racetrack	-5.64605	-5.4482371

As can be seen, the results obtained from SYNCH, MAD, PATRICIA, PATPET and MARYLIE are in agreement, with some differences in the results obtained from HARMON and RACETRACK.

Tables VIa and VIb presents the variations of the betatron tunes (Q_x,Q_y) and chromaticities for the Booster with respect to variations in momentum obtained with programs MAD6 and SYNCH respectively.

Table VIa. AGS Booster with MAD6

Δp/p	Q_x	Q_y	C_x	C_y
-0.01	4.869524	4.882689	-4.974135	-5.314419
-0.004	4.839755	4.851065	-4.947183	-5.284184
0.000	4.820000	4.829999	-4.929702	-5.264883
+0.004	4.800317	4.808946	-4.912583	-5.246156
+0.010	4.770922	4.777389	-4.887536	-5.219016

Table VIb. AGS Booster with SYNCH

Δp/p	Q_x	Q_y	C_x	C_y
-0.0100	4.87006	4.88460	-5.03758	-5.60968
-0.00400	4.83984	4.85137	-4.97202	-5.40198
0.0000	4.82000	4.83000	-4.92970	-5.26488
0.00400	4.80040	4.80925	-4.88841	-5.12853
0.01000	4.77144	4.77930	-4.82823	-4.92924

Comparisons of the lattice parameters shows a good agreement between values of the lattice functions, tune shifts, etc. for Δp/p=0 for most of the codes, but somewhat different for Δp/p≠0, as can be seen from Tables VIa and VIb, (results obtained from programs SYNCH and MAD). The discrepancies become larger when sextupoles are included in the input lattices for δ≠0. With correction sextupoles the Booster chromaticity (at δ=0) reduces to (0.0,0.0) calculated with SYNCH and (0.001048,-0.001678) calculated with MAD6 (at the same nominal tunes). From the HFUNCT in HARMON, the variations of tune shift with momentum (δ=Δp/p) become:

$$\Delta Q_x = -0.311481\delta + 28.93758\delta^2 - 162.218\delta^3$$
$$\Delta Q_y = -3.313248\delta + -43.88808\delta^2 - 21.53088\delta^3\,,$$

where the chromaticity becomes $C_x=-0.311481$ and $C_y=-3.3132$ for δ=0. Figure 6 shows the chromaticity changes with momentum for the Booster lattice with no sextupoles with MAD6 and SYNCH.

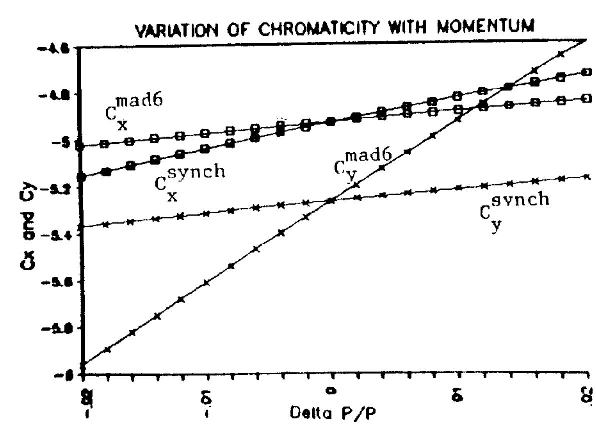

Fig. 6 Booster with MAD6 & SYNCH.

Tables VII gives the comparison of the uncorrected chromaticity for the proposed Relativistic Heavy Ion Collider (RHIC) at BNL (at δ=0) and Tables VIIa and VIIb shows the variations of the tunes and the chromaticity with momentum for RHIC with SYNCH and MAD6 respectively.

Table VII. Natural Chromaticity (C_x,C_y) Calculated for RHIC

Program	C_x	C_y
SYNCH*	-56.82647	-56.73516
MAD6**	-56.825021	-56.738819
HARMON (Hfunct)	-56.97291	-56.81275
HARMON (Hchrom)	-56.9142	-56.8084
RACETRACK	-56.7834824	-56.7726791

* tunes of (28.82648,28.82236).
**tunes of (28.826941,28,82297)

Table VIIa. RHIC with SYNCH

	Q_x	Q_y	C_x	C_y
-0.01	28.81332	28.83524	3.09162	-2.54571
-0.004	28.82506	28.82439	0.95546	-1.01525
0.000	28.82694	28.82230	0.05677	-0.01103
+0.004	28.82627	28.82442	-0.28302	1.12055
+0.01	28.82673	28.83748	0.85609	3.46690

Table VIIb. RHIC with MAD

	Q_x	Q_y	C_x	C_y
-0.01	28.724101	28.726098	25.340563	23.528259
-0.004	28.812714	28.809072	7.190661	6.737079
0.00	28.826941	28.822297	0.147893	0.073932
0.004	28.814661	28.810332	-6.307358	-6.075735
0.01	28.742730	28.741085	-18.934403	-18.215989

Table VIII. Natural Chromaticity (C_x,C_y) for XLS (XUV Cosy Ring, and Parallel Chasman Green Lattice)

Program	C_x	C_y
SYNCH	-4.09957	-4.35521
MAD6	-4.099566	-4.355212
PATRICIA88.4	-4.17811	-4.14091
PATPET88.2	-4.17811	-4.14091
DIMAD	-4.0995	-4.3552
BETA	-4.0995	-4.3553
MARYLIE		

The results obtained from SYNCH, MAD, DIMAD and BETA (for the parallel end magnets) are in agreement, but there are some discrepancies with the results of HARMON, PATRICIA and MARYLIE (see Table VIII).

Table IX. Natural Chromaticity (C_x,C_y) for SXLS (sector magnet)

Program	C_x	C_y
SYNCH	-0.46896	-1.28953
MAD6	-0.468960	-1.289534
PATRICIA88.4	-0.46896	-1.28955
PATPET88.2	-0.46896	-1.28955
DIMAD	-0.46895	-1.28953
MARYLIE3.1	-0.37701711	-1.97219310

For lattice with sector magnets such as SXLS, the results obtained from SYNCH, MAD6, PATRICIA, PATPET and DIMAD are in agreement[10] but there is a discrepancy with the results of MARYLIE.

Table X. Natural Chromaticity (C_x,C_y) for X-Ray Ring (Parallel Magnets)

Program	C_x	C_y
SYNCH	-22.33733	-16.59485
MAD	-22.3373	-16.5949

The result of SYNCH and MAD are in agreement as shown above, but there are discrepancies in the results obtained from the other programs (due to space limitation were not included), and some could not give any results. The combined function with parallel edge magnets are not handled well with most of these programs.

IV. Conclusion

Comparison of the lattice parameters shows a good agreement between the values of the tune shift, lattice functions, etc. for $\delta=0$, for most of the codes examined. There are discrepancies in the results for $\delta\neq0$ and becomes larger when the sextupoles are included. The differences in the chromaticity calculation in these programs depends on the methods of integration used to evaluate the integrals across the elements (e.g. exact integration method used across the quadrupole lengths in one code versus numerical integration in another code) and the way the fringe fields are treated. The quadrupole fringe fields are ignored in most codes and could be detrimental to the design especially for the long and narrow or short and wide magnets. We note that, the combined function with parallel edge magnets are not handled well with most of the programs, (e.g. X-RAY ring). More detailed analysis of our results with each of these programs is available, but due to space limitation is not included here. Since the input format to most of the codes varies, at most care must be taken to assure the input consistency to all the codes. In that some of our input and results for programs PATRICIA, MARYLIE and SYNCH were checked and confirmed by the authors of these codes; H. Wiedemann, A. Dragt and E. Courant respectively. We appreciate receiving comments, informations and updated versions of the codes from the authors of these programs.

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References

[1] A. Garren, principal author (P.A.), we have used SYNCH88.5 version at BNL.

[2] F.C. Iselin, CERN (P.A.), MAD6 version.

[3] M. Donald, SLAC (P.A.), HARMON in MAD6 version.

[4] H. Wiedeman, SLAC (P.A.), PATRICIA88.4, PATPET88.2.

[5] L. Farvacque (P.A.), BETA 1987 version.

[6] R. Servranckx (P.A.), 1985 version.

[7] A. Dragt (P.A.), MARYLIE 3.01.

[8] A. Wrulick, (P.A.), from S. Kramer, (ANL) (1987).

[9] Parameters for the X-ray rings (and instruction manual for BETA) was received from J. Murphy, private communication).

[10] e.g. See A. Dragt, Part. Accel., Vol. 12, 205 (1982); M. Bassetti, LEP Note 504 (1984).

[11] Z. Parsa, BNL 39311; Booster Design Manual.

[12] For comparison of non-linear effects in SSC and Booster see Z. Parsa, Proc. of 1986 Summer Study on Physics of SSC, Snowmass, CO, and Proc. of 1987 IEEE Part. Acc. Conf., Washington, D.C., Vol. 2, #87CH2387-9.