COMPUTING TOOLS FOR ACCELERATOR DESIGN*

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Abstract

We have developed an algorithm that calculates and obtains information about nonlinear contributions in accelerators. The comparison of the results obtained from this program "NONLIN" and HARMON is discussed and illustrated for the SSC-CDR clustered lattices.

I. Introduction

We have investigated the nonlinear effects on the dynamical systems, (e.g., circular accelerators) and have implemented some of our results in an algorithm that calculates and obtains information about nonlinear effects in accelerators [1] including: the perturbation of tune; emittance growth; "smear"; linear aperture; Hamiltonian resonance strength; generating function resonance strength; fixed points; Chirikov criterion; island width, etc. The structure resonances for the SSC-CDR lattices for $\beta^* = 0.5$ and $\beta^* = 6$ were investigated using this program ("NONLIN").

In this note, we also compare our results obtained from NONLIN [2] with those obtained from HARMON [3,4] for the same lattices [3]. In section II, we describe the differences in the notations of these programs. The conclusion is given in section III, and the results obtained from these programs for the SSC-CDR lattices are tabulated and labeled as NONLIN and/or HARMON respectively in section IV.

For a given (Table number) lattice the Tables labeled with "[NONLIN]" corresponds to the same Tables labeled with "[HARMON]".

II. Programs' Notation:

The following differences between the notations and magnitudes in the results obtained from programs HARMON and NONLIN should be noted and are given for clarity:

The stop bandwidths (given under the heading of "DQ") in the HARMON output is twice as large as the stop bandwidth obtained from NONLIN's output (given under the heading "stp bnw"), because, the stop bandwidth calculated from HARMON is over the full width of the interval whereas NONLIN calculates over half of the interval.

We calculate two different resonance strengths, the Hamiltonian and the generating function resonance strengths. The resonance strengths obtained from HARMON's output which is normalized (under the "MODULUS" heading) when multiplied by

$$E_x^{(|n_x|/2)} \; E_z^{(|n_z|/2)}$$

[where E_x and E_z are the transverse beam emittances], corresponds to the Hamiltonian resonance strength obtained from NONLIN's output (under the heading of "Strength" given next to the stop bandwidth column). Furthermore, the perturbation to tunes in NONLIN (i.e., the Q shift parameters in HARMON) are the same as those calculated by HARMON.

Conclusion

In this paper we have given some of the preliminary results obtained from the program "NONLIN" that was used to calculate (and obtain information about) the nonlinear effects in the SSC lattices. The comparison of our results using NONLIN and the program HARMON is given for the investigation of nonlinear effects in accelerators.

We find that the results between HARMON and NONLIN agrees qualitatively for the lattices tested [2-4,6](i.e., the strength of resonances may agree qualitatively but not quantitatively).

These programs agree quantitatively, in tune shift parameters and the stop bandwidth calculation for the third order resonances [see Tables in section IV]. The differences in the stop bandwidths of the other resonances may be due in part to the difference in the canonical transformations used on the Hamiltonian.

Additionally, we can calculate the beam emittance growth; variation in the particle action; "smear"; linear aperture; sixth order resonances; the Chirikov criterion (i.e., to determine when two or more resonances could lead to chaotic behavior), and generating function resonance strength with preliminary version of NONLIN (as was illustrated in the previous section, and can be seen from the following tables).

TABLE I-A [NONLIN]

CDR LATTICE FOR SSC BET*=6.

Perturbation of tunes

vx = vx0 + -716.3168 * Ex + -2445.579 * Ez
vy = vz0 + -2445.579 * Ex + -477.6593 * Ez

where the unperturbed betatron tunes are
vx0 = 78.26496 and vz0 = 78.27999
with circumference = 82944.00
and periodicity = 1

Given a beam with emittances
Ex = 2.4939999E-07 and Ez = 2.4939999E-07
(*pi m-rad),
the perturbed tunes become
vx = 78.26417 and vz = 78.27927

The emittance can grow to
Exmax = 2.7996103E-07 at the 43 th element and
Ezmax = 2.7773686E-07 at the 7 th element.

The smear is found to be
Smear= 1.5864842E-02 at the 43 th element and
Smear= 1.5863875E-02 at the 7 th element

The linear emittance when the smear = .1 is
Elin = 1.5132670E-06 at the 43 th element and
Elin = 1.5134377E-06 at the 7 th element

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TABLE I-B [NONLIN]

CDR LATTICE FOR SSC BET*=6.
The resonances are numbered as follows:

No.	Resonance	Fix pts.	Strength Width	Stp bndw Chirikov cr
1A	0 vx +2 vz = 156	1.6352E-05	9.2759E-13 2.2034E-08	1.4877E-05 1.2756E-08
1B	0 vx +2 vz = 157	1.8145E-08	1.0190E-15 7.3028E-10	1.6343E-08 4.2279E-10
2A	0 vx +4 vz = 313	3.9350E-08	1.1625E-15 1.9500E-10	7.4577E-08 9.0316E-10
2B	0 vx +4 vz = 314	1.2648E-05	3.6566E-13 3.4585E-09	2.3459E-05 1.6018E-08
3A	1 vx -2 vz = -79	5.6760E-04	1.4156E-10 0.0000E+00	1.7028E-03 0.0000E+00
3B	1 vx -2 vz = -78	2.6865E-08	6.7001E-15 0.0000E+00	8.0594E-08 0.0000E+00
4A	1 vx +0 vz = 78	1.9978E-07	3.0714E-14 0.0000E+00	1.2315E-07 0.0000E+00
4B	1 vx +0 vz = 79	2.3932E-03	3.6928E-10 0.0000E+00	1.4807E-03 0.0000E+00
5A	1 vx +2 vz = 234	6.1561E-07	5.1178E-14 0.0000E+00	1.0260E-06 0.0000E+00
5B	1 vx +2 vz = 235	1.0346E-04	8.6008E-12 0.0000E+00	1.7243E-04 0.0000E+00
6A	2 vx -4 vz = -157	0.0000E+00	1.7968E-16 7.9233E-11	4.3227E-09 6.8715E-10
6B	2 vx -4 vz = -156	0.0000E+00	1.2893E-13 2.1224E-09	3.1018E-06 1.8407E-08
7A	2 vx -2 vz = -1	1.2893E-07	8.9075E-15 7.7609E-10	1.4286E-07 3.4778E-09
7B	2 vx -2 vz = 0	1.3015E-03	8.9925E-11 7.7978E-08	1.4423E-03 3.4943E-07
8A	2 vx +0 vz = 156	1.5685E-05	7.2071E-13 1.5860E-08	1.1559E-05 1.3769E-08
8B	2 vx +0 vz = 157	1.6868E-08	1.0819E-15 6.1448E-10	1.7352E-08 5.3349E-10
9A	2 vx +2 vz = 313	5.3576E-08	1.6702E-15 2.6195E-10	5.3576E-08 1.9320E-09
9B	2 vx +2 vz = 314	1.6455E-05	5.1299E-13 4.5908E-09	1.6455E-05 3.3859E-08
10A	2 vx +4 vz = 469	1.0609E-05	2.0670E-13 2.0407E-09	1.6576E-05 3.0692E-08
10B	2 vx +4 vz = 470	2.2459E-03	4.3760E-11 2.9692E-08	3.5092E-03 4.4657E-07
11A	3 vx +0 vz = 234	7.2906E-07	2.0203E-14 0.0000E+00	7.2906E-07 0.0000E+00
11B	3 vx +0 vz = 235	1.2613E-04	3.4952E-12 0.0000E+00	1.2613E-04 0.0000E+00
12A	4 vx -2 vz = 156	1.2126E-06	7.5609E-14 8.5665E-10	1.8190E-06 1.3372E-08
12B	4 vx -2 vz = 157	4.3560E-10	2.7160E-17 1.6236E-11	6.5340E-10 2.5344E-10
13A	4 vx +0 vz = 313	3.6246E-08	6.8462E-16 1.2220E-10	4.3921E-08 8.4877E-10
13B	4 vx +0 vz = 314	1.3200E-05	2.3752E-13 2.2762E-09	1.5238E-05 1.5809E-08
14A	4 vx +2 vz = 469	7.7782E-08	1.6166E-15 8.7737E-11	1.2964E-07 2.7915E-09
14B	4 vx +2 vz = 470	1.2545E-05	2.6073E-13 1.1142E-09	2.0908E-05 3.5451E-08
15A	6 vx +0 vz = 469	4.4857E-06	4.6614E-14 4.4816E-10	6.7285E-06 1.0505E-08
15B	6 vx +0 vz = 470	9.2932E-04	9.6572E-12 6.4506E-09	1.3940E-03 1.5121E-07

TABLE I-C [NONLIN]

CDR LATTICE FOR SSC BET*=6.
The generating function resonance strength
for the resonances:

Chromaticity sextupoles	Resonance numbers 1	2	3
43	6.84477E-12	1.27363E-12	1.00860E-09
	4	5	6
	2.74030E-09	2.59494E-10	3.84700E-12
	7	8	9
	1.12059E-09	1.36535E-11	7.96476E-13
	10	11	12
	2.24002E-10	9.89518E-11	6.82071E-13
	13	14	15
	3.61567E-13	1.42736E-12	4.54290E-11
Elements	1	2	3
7	6.97217E-12	1.30371E-12	1.00845E-09
	4	5	6
	2.73891E-09	2.59353E-10	3.86933E-12
	7	8	9
	1.12059E-09	1.36619E-11	8.46263E-13
	10	11	12
	2.24590E-10	9.88886E-11	6.77308E-13
	13	14	15
	3.67257E-13	1.42967E-12	4.55659E-11

TABLE I-A [harmon]

HARMON - CDR LATTICE FOR SSC WITH BETA*=6.
[INITIAL EMITTANCE: Ex0= Ez0 = 2.4940E-07]

TOTAL LENGTH = 82944. NSUP = 1
QX = 7.82650E+01 QZ = 7.82800E+01
BETAX = 1.11371E+02 BETAZ = 3.31656E+02
ETAX = 2.36230E+00

NORMALIZED STRENGTHS

ID	STRENGTH
SF	5.12380E-03
SD	-8.25720E-03

FOURTH ORDER EFFECTS OF SEXTUPOLES
Q SHIFT EFFECTS

	G22000	DQXDEX	DQX
-3.58180E+02	2.14884E-12	-7.16360E+02	-1.78660E-04
	G00220	DQYDEY	DQY
-2.38812E+02	1.29191E-12	-4.77625E+02	-1.19120E-04
	G11110	DQXDEY	DQYDEX
-2.44556E+03	1.02414E-11	-2.44556E+03	-2.44556E+03
		DQX	DQY
		-6.09923E-04	-6.09923E-04

RESONANCE EFFECTS
[G's are the 2nd order coefs.]

	COS	SIN DQ	DE DQ(20)
G4000,313	2.5856E-04	-1.0971E-04	1.1208E-09
		6.7646E-10	9.7866E-10
G0040,313	1.7267E-05	-1.5545E-04	6.2414E-10
		3.7670E-10	5.4499E-10
G2020,313	-2.9871E-04	-5.5839E-04	1.2635E-09
		1.0785E-09	1.5602E-09
G2002, 0	6.0136E+02	1.1105E+02	6.1153E+02
G4000,314	3.6264E-01	-4.1347E-01	2.1946E-06
		1.3246E-06	1.9163E-06
G0040,314	4.8055E-01	-2.9350E-01	2.2469E-06
		1.3562E-06	1.9620E-06
G2020,314	7.3629E-01	1.2623E-01	1.4905E-06
		1.2722E-06	1.8406E-06
G2002, 1	2.7284E-02	1.5417E-02	3.1338E-02

TABLE I-B [harmon]

HARMON - CDR LATTICE FOR SSC WITH BETA*=6.
[Initial Emittance: Ex0 = Ez0 = 2.4940E-07]

COSINE DE(S)	SINE DE(R)	MODULUS DQ(S) DQ20(S)	RANDOM DQ(R) DQ20(R)
FOURIER ANALYSIS. ORDER OF RESONANCE = 1			
Qx = 78.			
-6.3516E-07	-1.4859E-06	1.6159E-06	7.3111E-01
3.2358E-03	1.4640E+03	3.2358E-03	1.4640E+03
		3.2358E-03	1.4640E+03
Qx = 79.			
-9.8864E-04	-1.9764E-02	1.9788E-02	7.3111E-01
3.9624E+01	1.4640E+03	3.9624E+01	1.4640E+03
		3.9624E+01	1.4640E+03
FOURIER ANALYSIS. ORDER OF RESONANCE = 2			
2Qx = 156.			
8.5630E-02	4.0122E-02	9.4563E-02	2.7255E+00
3.7825E-01	1.0902E+01	1.8913E-01	5.4511E+00
		1.8913E-01	5.4511E+00
2Qz = 156.			
-2.1020E-02	1.6284E-01	1.6419E-01	3.8994E+00
6.5677E-01	1.5598E+01	3.2838E-01	7.7988E+00
		3.2838E-01	7.7988E+00
2Qx = 157.			
-1.0742E-05	-5.6483E-06	1.2136E-05	2.7255E+00
4.8545E-05	1.0902E+01	2.4272E-05	5.4511E+00
		2.4272E-05	5.4511E+00
2Qz = 157.			
1.2857E-05	-9.3333E-08	1.2858E-05	3.8994E+00
5.1431E-05	1.5598E+01	2.5716E-05	7.7988E+00
		2.5716E-05	7.7988E+00

TABLE I-C [harmon]

HARMON - CDR LATTICE FOR SSC WITH BETA*=6.
[INITIAL EMITTANCE: Ex0= Ez0 = 2.4940E-07]

COSINE DE(S)	SINE DE(R)	MODULUS DQ(S) DQ20(S)	RANDOM DQ(R) DQ20(R)
FOURIER ANALYSIS. ORDER OF RESONANCE = 3			
3Qx = 234.			
1.6132E-04	1.3147E-05	1.6185E-04	7.4714E+00
1.4549E-06	6.7162E-02	4.8497E-07	2.2387E-02
		1.0023E-06	4.6267E-02
Qx + 2Qz = 234.			
2.2752E-04	3.4173E-04	4.1055E-04	2.1756E+01
2.0503E-06	1.0865E-01	9.1691E-07	4.8588E-02
		1.8949E-06	1.0042E-01
-Qx + 2Qz = 78.			
3.0156E-05	-3.7527E-05	4.8142E-05	2.1756E+01
3Qx = 235.			
-2.5380E-02	-1.1974E-02	2.8062E-02	7.4714E+00
2.5226E-04	6.7162E-02	8.4086E-05	2.2387E-02
		1.7378E-04	4.6267E-02
Qx + 2Qz= 235.			
-1.6364E-02	-6.7091E-02	6.9058E-02	2.1756E+01
3.4487E-04	1.0865E-01	1.5423E-04	4.8588E-02
		3.1875E-04	1.0042E-01
-Qx + 2Qz = 79.			
COSINE	SINE	MODULUS	RANDOM
9.5364E-01	-6.1833E-01	1.1366E+00	2.1756E+01

TABLE I-D [harmon]

HARMON - CDR LATTICE FOR SSC WITH BETA*=6.

[INITIAL EMITTANCE: Ex0 = Ez0 = 2.4940E-07]

COSINE DE(S)	SINE DE(R)	MODULUS DQ(S) DQ20(S)	RANDOM DQ(R) DQ20(R)
FOURIER ANALYSIS. ORDER OF RESONANCE = 4			
4Qx = 313.			
-2.8860E-04	-4.8607E-05	2.9266E-04	1.6180E+01
2.8194E-09	1.5587E-04	7.0485E-10	3.8967E-05
		1.0197E-09	5.6375E-05
2Qx + 2Qz = 313.			
-8.6381E-04	-7.1929E-04	1.1241E-03	6.4319E+01
5.4145E-09	3.0981E-04	1.9143E-09	1.0954E-04
		2.7695E-09	1.5847E-04
4Qz = 313.			
-1.8434E-04	-2.7677E-04	3.3254E-04	2.5612E+01
3.2036E-09	2.4674E-04	8.0089E-10	6.1684E-05
		1.1587E-09	8.9240E-05
2QX -2QZ = 0.			
COSINE	SINE	MODULUS	RANDOM
-1.8668E+02	0.0000E+00	1.8668E+02	6.4319E+01
4Qx = 314.			
-6.1293E-01	-3.7561E-01	7.1887E-01	1.6180E+01
6.9253E-06	1.5587E-04	1.7313E-06	3.8967E-05
		2.5048E-06	5.6375E-05
2Qx + 2Qz = 314.			
-1.5619E+00	-2.8292E+00	3.2317E+00	6.4319E+01
1.5567E-05	3.0981E-04	5.5036E-06	1.0954E-04
		7.9623E-06	1.5847E-04
4Qz = 314.			
-2.6192E-01	-1.1006E+00	1.1314E+00	2.5612E+01
1.0899E-05	2.4674E-04	2.7248E-06	6.1684E-05
		3.9421E-06	8.9240E-05
2Qx-2Qz=1.			
COSINE	SINE	MODULUS	RANDOM
-7.7929E-03	-4.6573E-03	9.0785E-03	6.4319E+01

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