Tracking of proton driver lattice variants

Béla Erdélyi

Fermilab, April 13

ICFA-HB2002

- **Three lattice variants termed:**
  - FODO
  - Rearranged FODO
  - PD
- **Compute dynamic aperture of the following cases:**
  - ideal lattice
  - ideal lattice with horizontal sextupoles turned off
  - lattice with a set of realistic errors

The tracking method

- **COSY Infinity used for tracking:**
  - kinematic effects included
  - fringe fields neglected (sharp cutoff approximation)

- **Tracking with the map:**
  - **order 18** used
  - quick search for approximate DA by **Taylor tracking**
  - check results by **symplectic tracking** (optimal symplectification of order 18 map)
  - for ideal lattices, **7**th order effects still strong, higher orders almost always negligible

- **Initial conditions and number of turns:**
  - set up grid in **polar coordinates** in the **x-y** plane
  - steps of **0.5 cm** along radial direction
  - seven angles: **0°, 15°, 30°, 45°, 60°, 75°, 90°**
  - vanishing transversal momenta
  - track for **1000 turns**
  - DA along each angle = largest **r** for which all particles with smaller **r** survive

DA of the ideal lattices

- **FODO**

Direction	**DA [cm]**
0°	17.5
45°	10.0
90°	6.5

- **Rearranged FODO**

Direction	**DA [cm]**
0°	≈ 150
45°	19.0
90°	15.5

- **PD**

Direction	**DA [cm]**
0°	30.5
45°	13.5
90°	15.0

DA of the ideal lattices with horizontal sextupoles OFF

- **FODO**

Direction	DA [cm] HS ON	DA [cm] HS OFF
0°	17.5	≈ 110
45°	10.0	10.5
90°	6.5	8.0

- **Rearranged FODO**

Direction	DA [cm] HS ON	DA [cm] HS OFF
0°	≈ 150	≈ 182
45°	19.0	18.5
90°	15.5	15.5

- **PD**

Direction	DA [cm] HS ON	DA [cm] HS OFF
0°	30.5	≈ 131
45°	13.5	14.0
90°	15.0	10.0

A set of multipole errors

- **Realistic error set:**
  - taken from MI Technical Design Handbook
  - only the normal systematic dipole and quadrupole body errors included
  - dipole errors up to 14-pole, and quadrupole errors up to 20-pole

Multipole order	**Error $< b_n >$**	
	Dipole	**Quadrupole**
4	0.06	-
6	-0.4	0.5
8	0.04	5.85
10	0.33	-0.1
12	-0.01	-1.82
14	-0.03	0.21
16		1.41
18		-0.03
20		-0.8

DA of the lattices with multipole magnet errors

- **FODO**

Direction	DA [cm] (ideal)	DA [cm] (with errors)
0°	17.5	3.5
45°	10.0	1.5
90°	6.5	1.5

- **Rearranged FODO**

Direction	DA [cm] (ideal)	DA [cm] (with errors)
0°	≈ 150	3.5
45°	19.0	1.5
90°	15.5	1.5

- **PD**

Direction	DA [cm] (ideal)	DA [cm] (with errors)
0°	30.5	6.0
45°	13.5	2.0
90°	15.0	1.5

Analysis of the results

- **Results can be explained by analysis of the map:**
  - amplitude dependent tune shifts
  - resonance driving term strengths

- **Examples:**
  - Why is the horizontal DA of the ideal rearranged FODO so large compared to the other two?
    * Look at first and second order amplitude dependent tune shifts

Tune shift coefficient	**Rearranged FODO**	**FODO**
First order	-0.2	-8
Second order	-2	11828

- – Why does the vertical DA stay the same for the rearranged FODO and is decreasing for PD, when the horizontal sextupoles are turned off?
    * Look again at tune shifts

Tune shift coefficient	**Rearranged FODO**		**PD**	
Horizontal	HS ON	HS OFF	HS ON	HS OFF
First order	-2	-2	-7	-1
Second order	6548	6385	-28516	-8144
Vertical				
First order	0.1	-0.1	2	-6
Second order	154	188	-19	654

Analysis of the results (cont.)

- Why are the properties of the three lattices essentially the same when magnet errors are included?
- The largest tune shift coefficients are:

Tune shift coefficient	**FODO**	**Rearranged FODO**	**PD**
First order	144	94	150
Second order	4161514	3317155	2346097

- The dominating resonance driving terms are:

D. t. coef.	**FODO**	**R. FODO**	**PD**
Third order	of (1,0): 28	of (1,0): 22	of (3,0): 12
Fourth order	(2,-2): 18217	(2,-2): 14605	(2,-2): 33198
Fifth order	(1,0): 1160894	(1,0): 1174164	(1,0): 946206

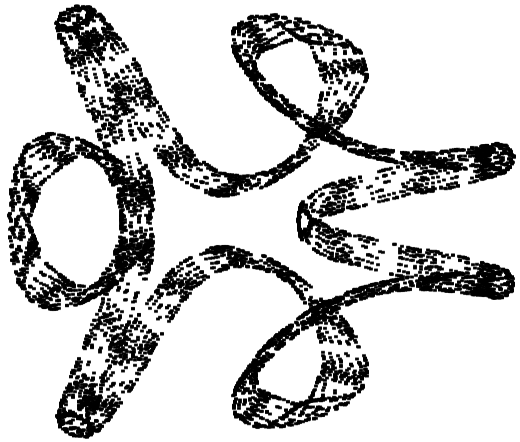
Summary and conclusions

- Three variants of a Proton Driver lattice have been investigated for dynamic aperture
- Emphasis was put on robustness studies with respect to multipole errors
- Ideal lattices showed a wide array of properties, mainly due to the positioning of the sextupoles
- The "accidental" cancellations of the ideal lattices in general do not survive under the presence of magnet errors
- Lattices with magnet errors show essentially the same behavior (with PD performing a tad better for this set of errors)

- Although no systematic study has been done, it seems that the choice of the tune alters the results quantitatively, but qualitatively the same conclusions can be drawn

Symplectic tracking

0.100E-01



0.400