The Los Alamos Proton Storage Ring for Code Benchmarking

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Alex Dragt's 1982 Paper Provides Useful Benchmarks

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EXACT NUMERICAL CALCULATION OF CHROMATICITY IN SMALL RINGS

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A purely numerical method, which is both conceptually simple and exact, has been developed for chromaticity calculations. Its use can therefore serve as a benchmark for checking other methods. The method employs a numerical integration procedure which simultaneously integrates the equations of motion for a particle trajectory and the variational equations for neighboring trajectories. A rapidly convergent Newton's search procedure is used to find closed orbits, and the solution to the variational equations provides the tunes of these orbits. It is found that the natural chromaticity of a small ring can vary widely over the tune diagram; and, contrary to common lore, can even be positive. It is also found that nonlinear dipole contributions can be very important for small rings. Finally, it is found that fringe fields, even in the hard edge approximation, can have nonlinear effects which influence chromaticities. Consequently, methods of chromaticity calculation which treat dipoles and fringe fields in the linear transfer matrix approximation are not expected to be correct for small rings.

Available at https://cds.cern.ch/record/890994/files/p205.pdf.

Sources of Chromaticity

Chromaticity measures the dependence of tunes on momentum, so ...

Bending and Focussing vary with momentum.

Closed Orbit (CO) varies with momentum.

What affects the tune?

CO path length varies with momentum

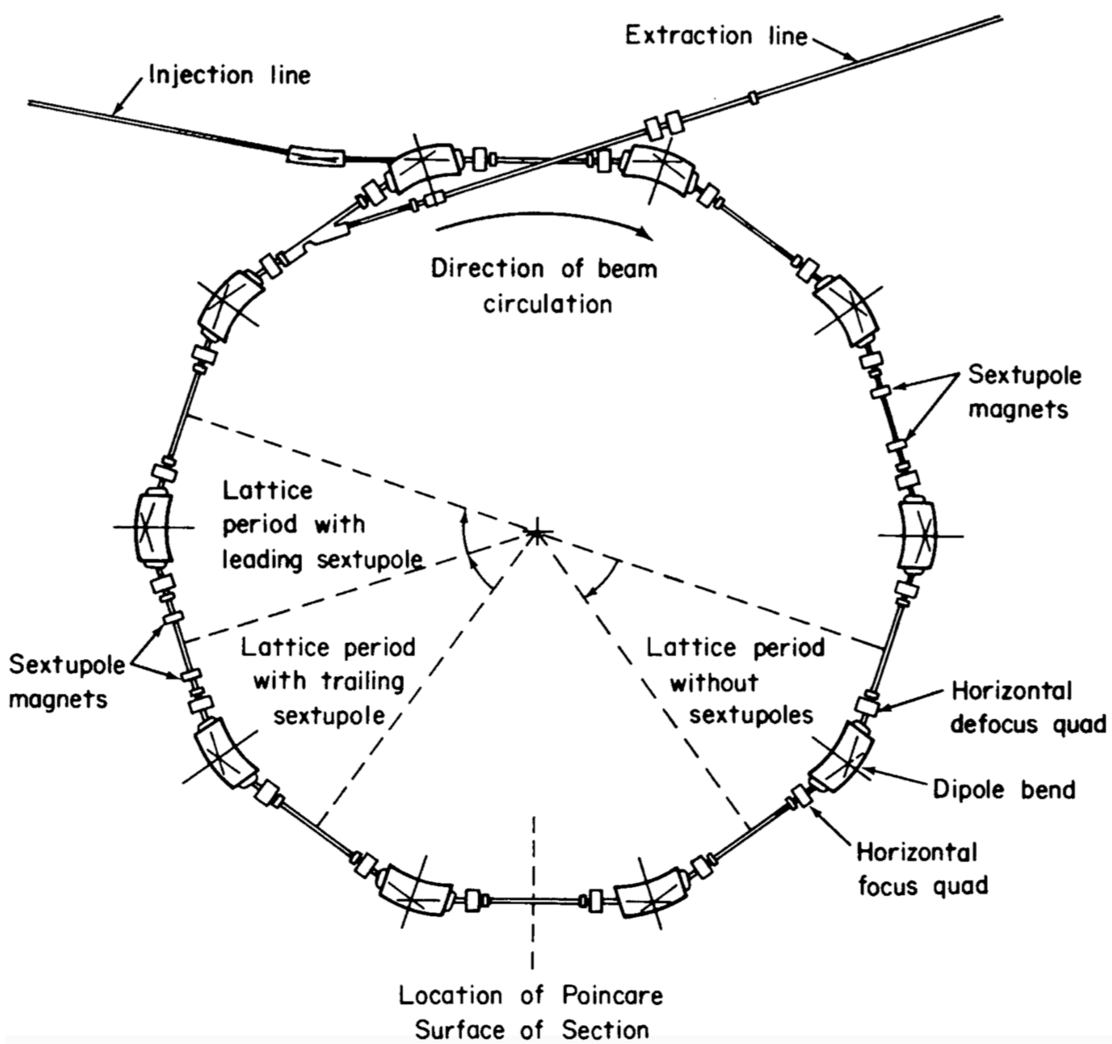
nonlinear fields lead to momentum dependent focussing (e.g. sextupoles)

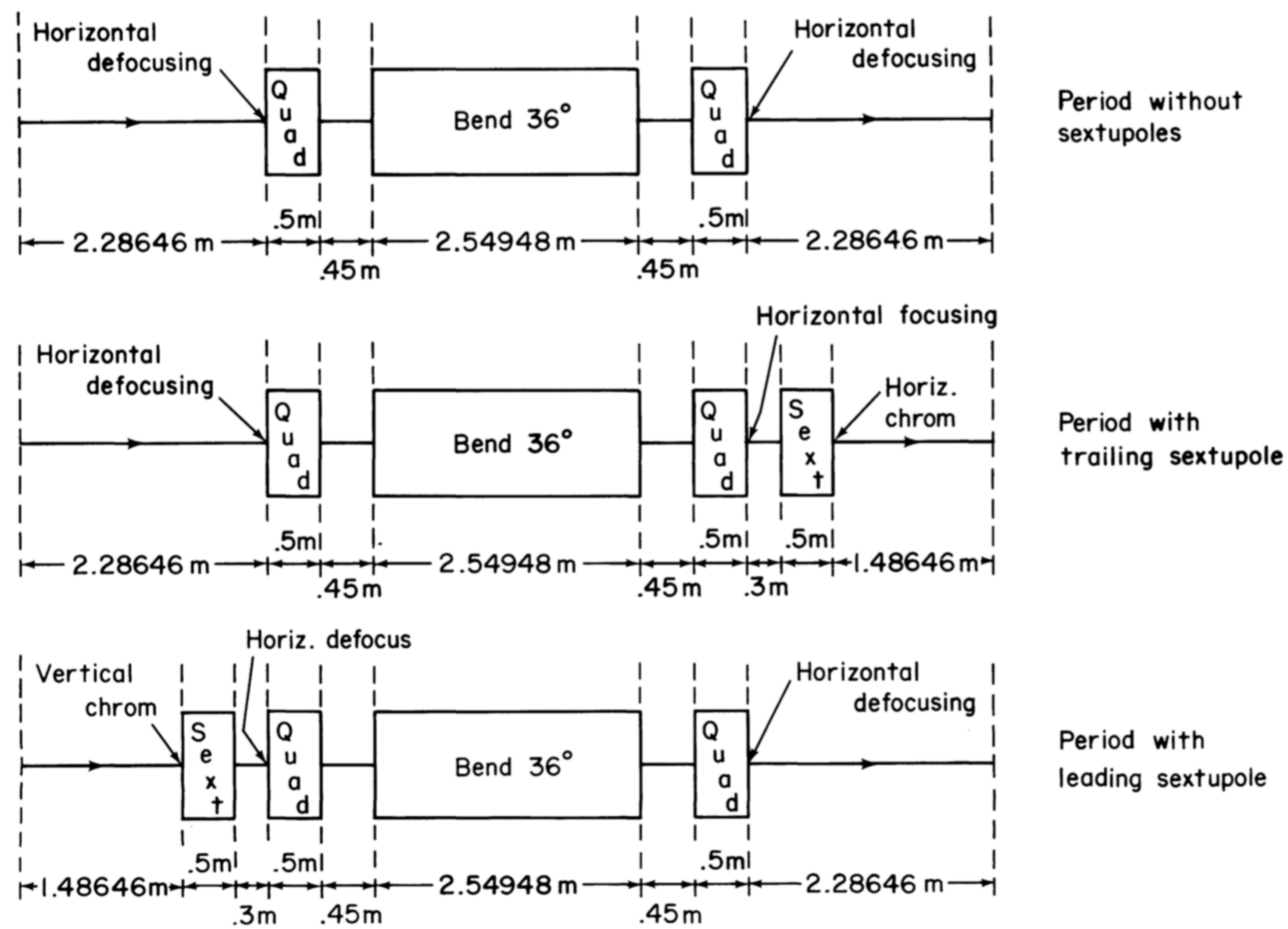
nonlinear terms in the dipole: $(C/\rho_0)\,(X - X_0)\,(P_x^2 + P_y^2)/(1 + \delta)$

fringe field focussing depends angles, hence the momentum dependent CO

$\Rightarrow$ Your computational model should capture these effects.

What did Alex do?





He started with a thorough description of the 10-cell PSR lattice, with an *excessive* number of significant digits (useful for benchmarking).

What did Alex do? — cont.

$$u_i' = f_i(\overrightarrow{u}, \theta), \quad i = 1 \ldots 4$$

$$\overrightarrow{u} = \overrightarrow{u}_\star(\theta) + \epsilon \overrightarrow{w}$$

$$\overrightarrow{w}' = \mathsf{A}_\star(\theta) \overrightarrow{w}$$

Integrate the (δ-dependent) CO and variational equations: 4 + 16 = 20 equations

Equations for individual elements derived from the appropriate Hamiltonian.

Included dynamic rotations to match angled elements.

What about fringe fields?

Effect of fringe on entering a dipole

$$X^a = X^b + \frac{1}{2}Y^2(1+\delta)^2\left[(1+\delta)^2 - (P_x^b)^2\right]^{-3/2} C/\rho_0$$

$$P_x^a = P_x^b$$

$$Y^a = Y^b$$

$$P_y^a = P_y^b - Y^b P_x^p\left[(1+\delta)^2 - (P_x^b)^2\right]^{-1/2} C/\rho_0$$

⇒ Limitation: short-fringe approximation and mid-plane symmetry

What did Alex do? — cont.

Fives scenarios for the Los Alamos PSR are given in tables:

Table II: sector bend, no sextupoles

TABLE II

Selected Closed Orbit Data for PSR with Normal Entry Bend Magnets

Horizontal Defocus Quad Strength = −2.68 Tesla/m
Horizontal Focus Quad Strength = 1.95 Tesla/m
All Sextupole Strengths = 0

δ	Q_y	P_y	T_h	T_v
0	0	0	2.2540596	2.2499258
10^{-3}	0.36722627-04	−0.33552032-03	2.2529848	2.2486430
-10^{-3}	−0.36703898-04	0.33513256-03	2.2551372	2.2512124
10^{-4}	0.36714206-05	−0.33534586-04	2.2539520	2.2497974
-10^{-4}	−0.36712333-05	0.33530708-04	2.2541673	2.2500543

Table III: same as II, but different quad strengths

Table IV: sector bend, with sextupoles on

Table V: rectangular bend, no sextupoles

Table VI: rectangular bend, with sextupoles on

Summary

The Los Alamos PSR is a low-energy, large curvature ring. This makes a good test of regimes not covered by typical high-energy approximations.

Dragt's 1982 paper provides a useful set of benchmarks. For especially careful comparisons, use the 1973 CODATA values of the relevant physical constants.

The fringe-field model has limitations.

Thank you!

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