PARTI Summer Intern Final Report

Multipole approximation of special nonlinear magnets for the IOTA ring.

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What is Integrable system?

- Integrable systems are those, which have the same number of integrals of motion and degrees of freedom. They provide stable enclosed trajectories.
- If the number of integrals of motion is less then the number of degrees of freedom, then the system can become chaotic.
- Present focusing lattices in accelerators are "linear" (consist of dipole and quadrupole magnets) and integrable.
- Linear motion is unstable to perturbations in the focusing fields and excludes any betatron tune spread over particle's energy. The focusing strength depends on the particle's energy deviation from the designed one.

Non-linear Integrable potential

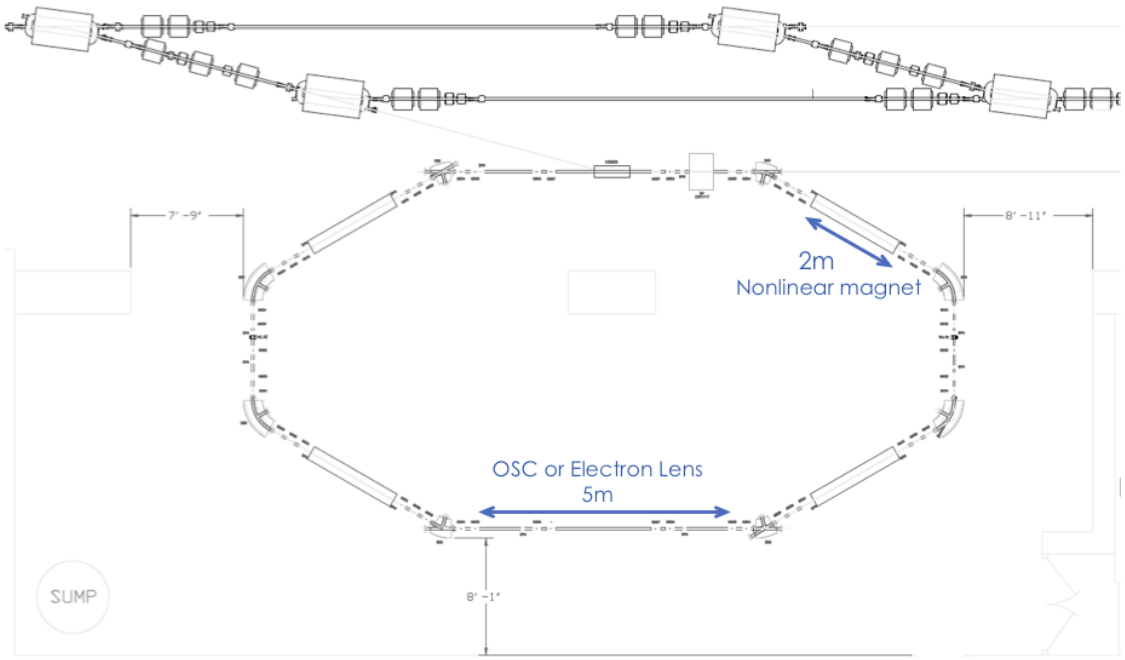
- Undesired effects in linear focusing optics are usually suppressed by the addition of non-linear elements, such as sextupoles and octupoles. Such approach leads to the loss of integrability.
- But there exist non-linear potentials that, nevertheless, are fully integrable. The one in elliptic coordinates has form

$$U(x,y) = \frac{x^2}{2} + \frac{y^2}{2} + \frac{f_2(\xi) + g_2(\eta)}{\xi^2 - \eta^2}$$

- There is an opportunity to create stable non-linear focusing optics that provides high betatron tune spread and mitigate magnetic field errors.

Integrable Optics Test Accelerator (IOTA) ring

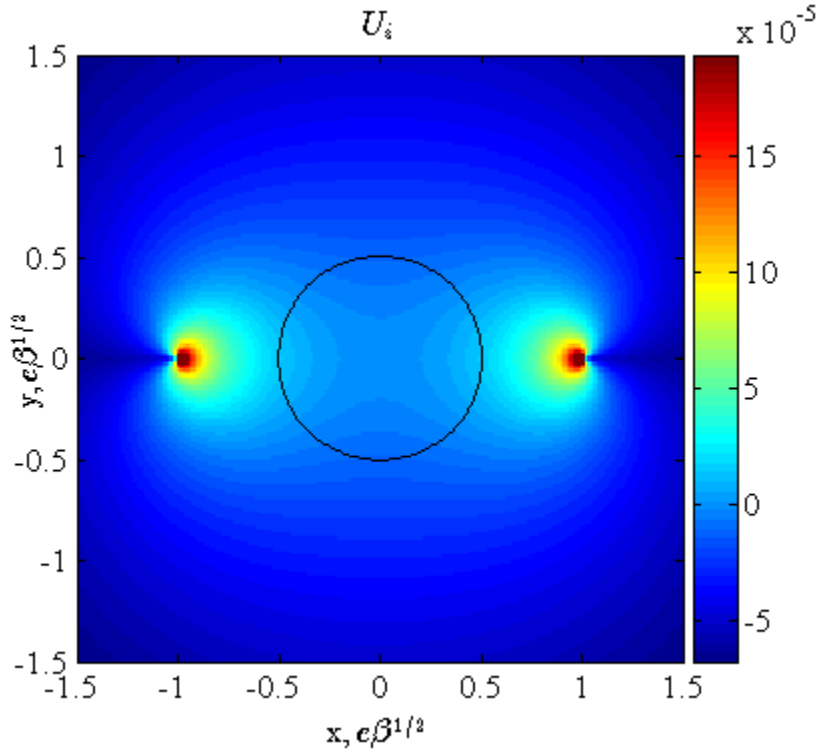
- This is electron storage ring for testing advanced accelerator physics concepts.
- The goal is to show the possibility to implement nonlinear integrable system in a realistic accelerator design.
- Design particle energy E = 150 MeV.
- The magnet that creates exact integrable non-linear potential is in the process of the development

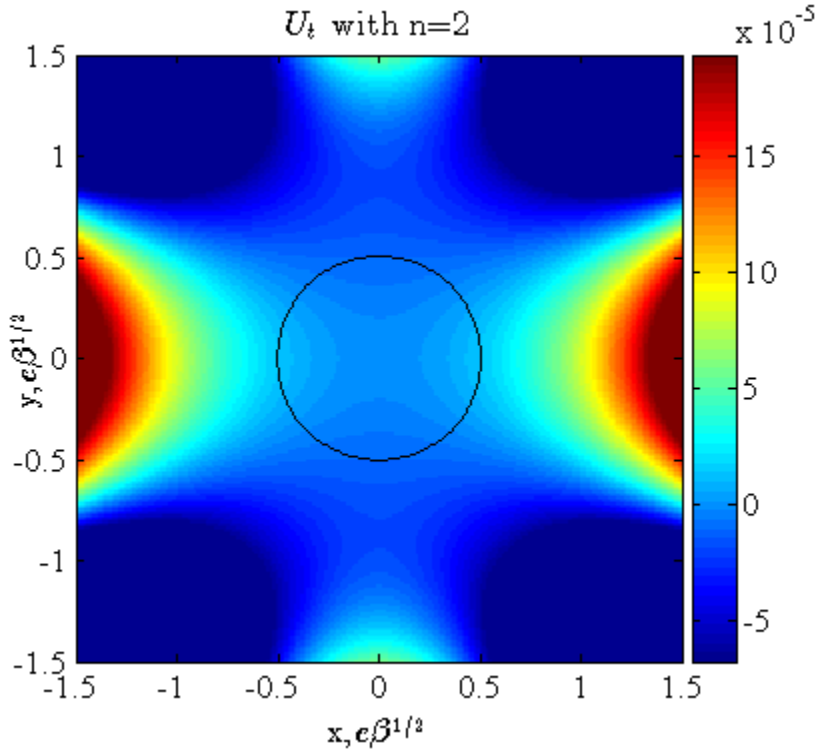


Multipole expansion

- This potential has two singularities, but can be expanded into series of multipoles of even orders inside area between these singularities

$$U(x_N, y_N) = -t\,\mathrm{Re}\left((x_N + iy_N)^2 + 2/3c^2\,(x_N + iy_N)^4 + 8/15c^4\,(x_N + iy_N)^6\right)$$

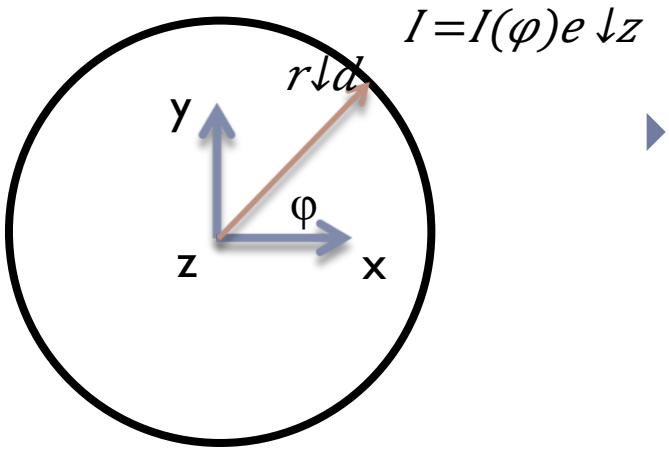




c and t are some constants, β is beta-function, potentials normalized on E/β

Internship Goal

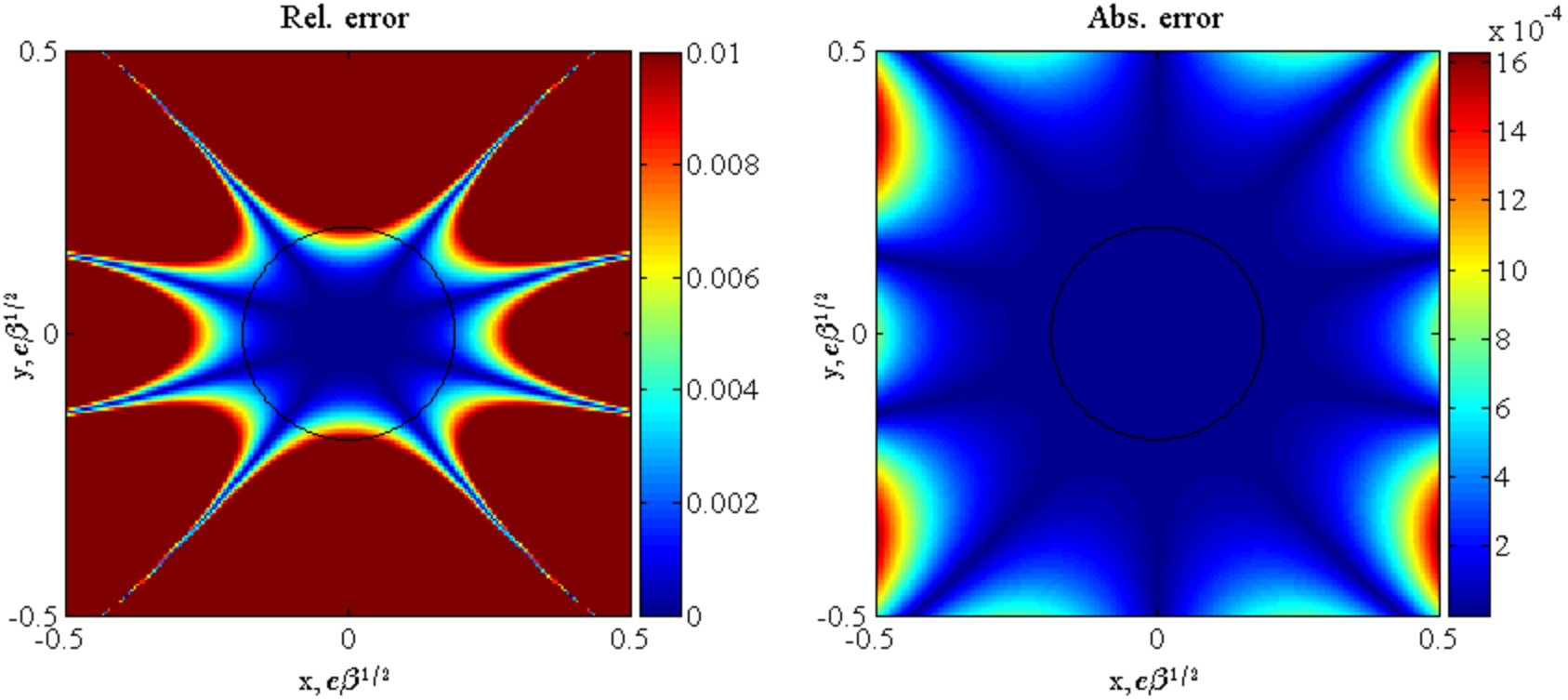
- **Consider** truncated potential, consisting of quadrupole and octupole terms
- **Calculate** current distribution on the surface of the accelerator's vacuum tube, that creates such potential



- **Develop** a model of coil made with flexible PCB (Printed Circuit Board), which provides desired current distribution.

Approximation by quadrupole and octupole terms

- Relative and absolute difference between $B\downarrow y$ components for exact and truncated potentials



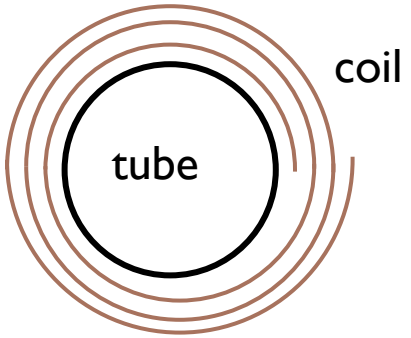
Absolute difference is given in E/(qvβ) units, where v is particle's velocity

Current distribution

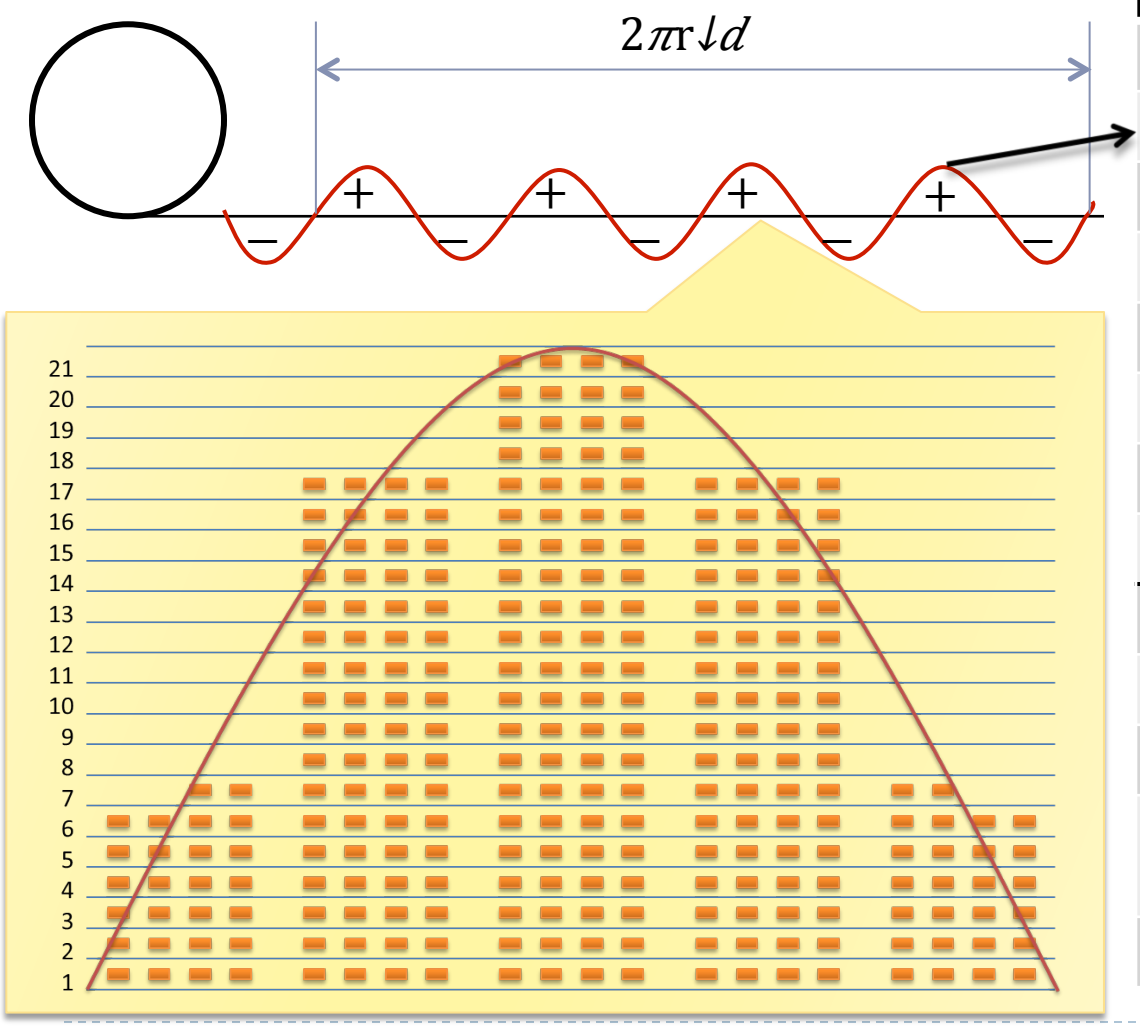
- Analytically was found that desired multipole potential is obtained by the following current on the surface of the tube with radius r_d

$$I(\varphi) = E/qZ_0 \; 4t/\beta^2 \; (r_d^2 \cos 2\varphi + 4/3\beta c^2 \cos 4\varphi)$$

- Amplitude of the current for the parameters initially laid into the design of IOTA turned up to be too high (~1kA for Q-term and ~12kA for O-term). This would result in too many turns of flexible PCB coil (2 A current source is supposed to be used).
- A program was made that generates a model of a coil (number of turns and distribution of wires in one layer) on given parameters of truncated potential.
- Also it was decided to eliminate quadrupole coil and use only octupole one. The one coil with a few number of turns was chosen.



Coil model



Parameter	Value
Tube radius	12.7 mm
Peak current	201.18 A
Wire thickness	0.035 mm
Wire width	0.25 mm
Wire current	0.37 A
Wire material	copper
Power/m	630 W/m
Current density	42 A/mm^2
# of turns	21
Insulator type	Kapton
Adhesive	Acryl/epoxy
Total substrate thickness/layer	0.05 mm
Total coil thickness	1.8 mm

*http://www.temflexcontrols.com/pdf/aa24.pdf

Summary and future plans

- Current distribution on the surface of vacuum tube for inducing of truncated potential was calculated.
- Program that generates a model of a coil for given terms in the expansion (actually, up to 7^{th} term, not only quadrupole and octupole) and various parameters is created.
- The coil consisting of octupole term is chosen for future development.

- Consider the side-effects of the chosen coil.

Thank you for attention!