International Research Journal in Global Engineering and Sciences. (IRJGES)
ISSN : 2456-172X | Vol. 2, No. 4, December - February, 2018
Pages 58-62 | Cosmos Impact Factor (Germany): 5.195
Received: 04.02.2018 Published : 28.02.2018

IOTA – Review of Critical Issues

K. Sathish Kumar, S. Kamatchi, M. Thavachelvam
Dhanalakshmi Srinivasan College of Engineering and Technology, Tamil Nadu, India

Abstract - The use of nonlinear lattices with large betatron tune spreads can increase instability and house cost thresholds due to improved Landau damping. Unfortunately, the majority of nonlinear accelerator lattices flip out to be nonintegrable, producing chaotic movement and a complicated community of secure and unstable resonances. Recent advances in finding the integrable nonlinear accelerator lattices have led to a inspiration to construct at Fermilab a take a look at accelerator with sturdy nonlinear focusing which avoids resonances and chaotic particle motion. This presentation will outline the most important challenges, theoretical design solutions and building repute of the Integrable Optics Test Accelerator (IOTA) underway at Fermilab. The Review of Critical Issues of IOTA is mentioned primarily based on the IOTA graph and non linear lenses.
Keywords: IOTA, Fermilab, Betatron

INTRODUCTION

In 1952 the groundbreaking work [1] of Courant, Livingston and Snyder has revolutionized the accelerators by way of introducing the principle of alternating-gradient (also acknowledged as strong) beam focusing. two They have found that an association of alternating (focusing-defocusing) quadrupole and dipole magnets can maintain the charged particle targeted on average. two Fundamentally, this is possible due to the fact the particle transverse motion, regardless of being time dependent, possesses two invariants of motion, recognized now as Courant-Snyder invariants. The existence of action invariants always simplifies the motion, introducing constraints on particle dynamics. If two commuting integrals of action exist, the particle's action (if finite) ought to be decreased to motion on tori in 4D segment space. All existing accelerators with robust focusing have the following property: particle transverse oscillation (betatron) frequency is through diagram unbiased of particle amplitude. The particle dynamics can be implicit by introducing the ostensible normalized phase-space coordinates:

$$z_N = \frac{z}{\sqrt{\beta(s)}},\qquad p_N = p\sqrt{\beta(s)} - \frac{\beta'(s)z}{2\sqrt{\beta(s)}}, \tag{1}$$

the place z stands for either x or y particle coordinates, p is in a similar way either px or py, and β(s) is either the horizontal or vertical beta-function. In these normalized coordinates the particle motion is same to that of a linear oscillator:

International Research Journal in Global Engineering and Sciences. (IRJGES)
ISSN : 2456-172X | Vol. 2, No. 4, December - February, 2018
Pages 44-49 | Cosmos Impact Factor (Germany): 5.195
Received: 24.02.2018 Published : 27.02.2018

$$\frac{d^2 z_n}{d\psi^2} + \omega^2 z_n = 0, \tag{2}$$

where ψ is the new "time", which is the betatron phase

$$\psi' = \frac{1}{\beta(s)}. \tag{3}$$

In this paper we will existing numerous examples of focusing systems, which are nonlinear by means of design, with the particle frequency being based on amplitude, yet stable and integrable. The benefits of such a gadget are two-fold. two First, the extended betatron frequency spread offers increased Landau damping. Second, a nonlinear gadget is extra secure to perturbations than a linear one [2]. There are merely a handful of nonlinear systems with single or two analytic integrals of motion for accelerators. The cause is that the nonlinear systems with analytic invariants are very uncommon in a large sea of nonlinear systems. In addition, for the focusing elements one has to use only the electromagnetic fields obeying the Maxwell equations. This, in turn, considerably reduces the variety of systems with invariants for practical use. two two two In the subsequent Section we describe the graph preference for the Integrable Optics Test Accelerator Ring (IOTA) aimed at trying out nonlinear focusing systems and different new accelerator thoughts as well. In the following we current what we assume are top candidates for first assessments of nonlinear structures producing massive frequency spreads and low particle loss.

IOTA DESIGN

The IOTA ring used to be designed for the proof-of-principle test of the nonlinear integrable optics idea [3] at the ASTA facility [4]. The preliminary version of the ring graph described in [5] used to be comprised of 4 periodic cells and had full 8-fold replicate symmetry. It was once later recognized that it is desirable to accommodate greater experiments, such as the nonlinear focusing with electron beam lens [6] and optical stochastic cooling. These choices demanded incorporation of a 5 m-long straight section. The experimental corridor dimensions allow to accommodate the stretched ring (Fig. 1) keeping the four 2 m nonlinear magnet insertions and the e- beam strength of 150 MeV. two Table 1 summarizes the major parameters of IOTA. The straight section opposite to the lengthy experimental insertion will be used for injection, RF cavity and instrumentation. The ring lattice is comprised of 50 traditional water-cooled quadrupole and eight dipole magnets. The beam pipe aperture is 50 mm.

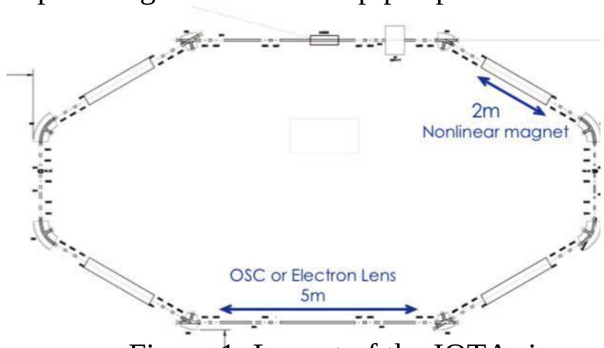

Figure 1: Layout of the IOTA ring.

International Research Journal in Global Engineering and Sciences. (IRJGES)
ISSN : 2456-172X | Vol. 2, No. 4, December - February, 2018
Pages 44-49 | Cosmos Impact Factor (Germany): 5.195
Received: 24.02.2018 Published : 27.02.2018

Table 1: Summary the main parameters of IOTA

Parameter	Value
Nominal beam energy	150 MeV(γ=295)
Nominal beam intensity	1×10^9 (single bunch)
Circumference	38.7 m
Bending field	0.7 T
Beam pipe aperture	50 mm dia.
Maximum β-function	3 ÷ 9 m
Momentum compaction	0.015 ÷ 0.1
Betatron tune	3.5 ÷ 7.2
Natural chromaticity	-5 ÷ -15
Transv. emittance, rms	0.02 ÷ 0.08 μm
SR damping time	0.5s (5×10^6 turns)
RF V, f, harmonic	75 kV, 162.5 MHz, 21
Synchrotron tune	0.005 ÷ 0.01

The goal of experiments at IOTA is to demonstrate the possibility to put into effect nonlinear integrable gadget in a realistic accelerator design. The project will concentrate on the scientific aspect of the single-particle movement steadiness in the nonlinear integrable system, leaving the research of collective effects and attainment of excessive beam present day to future lookup [7]. We intend to acquire the amplitude-dependent nonlinear tune shift exceeding 0.25 besides degradation of dynamic aperture.

NONLINEAR LENSES

Two instructions of nonlinear focusing factors can be regarded for the sensible implementation: (1) a cost column (an electron lens) type and (2) an external static field type. The later on is the majority restrictive because the static potentials in vacuum have to satisfy the Laplace equation. An electron lens [6] employs the area charge forces of a low-energy beam of electrons that interacts with the high-energy particle over an prolonged length, Le . The lens can be used as each linear and nonlinear focusing thing depending on the electron current-density distribution je(r) and the electron-beam radius ae.The first example of this kind is the so-called McMillan skinny lens. A 1-dimensional lens of this type was once first described through E. McMillan [8] and was once later extended into 2-d through Danilov and Perevedentsev [9]. For a thin lens approximation to be valid, the following situation have to be met: Le<e, <b="" title="where|where|the place" class="qtiperar" style="cursor: pointer; color: red;" id="tip_48">the place E is the beta-function at the electron lens location. The electron lens modern density has the following distribution: </e,>

$$j_e(r) \propto \frac{I_e}{\left(r^2 + a_e^2\right)^2}. \qquad (4)$$

International Research Journal in Global Engineering and Sciences. (IRJGES)
ISSN : 2456-172X | Vol. 2, No. 4, December - February, 2018
Pages 44-49 | Cosmos Impact Factor (Germany): 5.195
Received: 24.02.2018 Published : 27.02.2018

In this lens approximation such a cost distribution presents the following angular kick to a particle, passing thru the electron lens at radius r:

$$\delta r' = \frac{kr}{r^2 + a_e^2}. \qquad (5)$$

In order for this nonlinear gadget to be integrable, the IOTA ring need to have the following one-revolution linear transformation matrix:

$$\begin{pmatrix} cI & sI \\ -sI & cI \end{pmatrix} \begin{pmatrix} 0 & \beta & 0 & 0 \\ -\frac{1}{\beta} & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta \\ 0 & 0 & -\frac{1}{\beta} & 0 \end{pmatrix} \qquad (6)$$

where

$$c = \cos(\phi),\ s = \sin(\phi),\ I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \qquad (7)$$

and Ǿ is an arbitrary parameter. Figure 2 shows an example of the tune footprint, obtained by the Frequency Map Analysis [10]. The attainable maximum spread of betatron frequencies for a single electron lens is ~0.3.

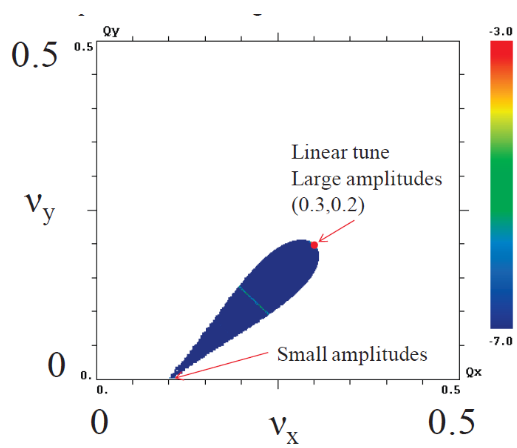

Figure 2: The fractional tune footprint in a thin-lens approximation (L<<β). For this simulation the 150-MeV IOTA beam used to be assumed to counter-propagate the electron lens beam cutting-edge of Ie×L = 0.5 A-m with a e = 1 The description of FMA simulation techniques can be found in Ref. [10].

The second instance of a nonlinear gadget using an electron lens does no longer require a thin-lens approximation. However, it requires an axially- symmetric electron lens modern density distribution. We have used the distribution (4) in our simulations. The thought is based totally on the following principle: the electron lens guiding solenoidal field (5 kG) is sufficiently excessive to focal point

International Research Journal in Global Engineering and Sciences. (IRJGES)
ISSN : 2456-172X | Vol. 2, No. 4, December - February, 2018
Pages 44-49 | Cosmos Impact Factor (Germany): 5.195
Received: 24.02.2018 Published : 27.02.2018

SUMMARY

In this paper we have introduced first realistic examples of completely integrable non-linear beam optics. These and different examples had been modelled with single-particle monitoring simulations [11] and confirmed the viability of this concept. The Integrable Optics Test Accelerator (IOTA) ring is now under construction with the completion predicted in 2014. The ring can also accommodate different Advanced Accelerator R&D experiments and/or users. Current design contains Optical Stochastic Cooling.

REFERENCES

[1] Courant, Ernest D., M. Stanley Livingston, and Hartland S. Snyder. "The strong-focusing synchroton—A new high energy accelerator." Physical Review 88.5 (1952): 1190.
[2] Nekhoroshev, Nikolai Nikolaevich. "An exponential estimate of the time of stability of nearly-integrable Hamiltonian systems." Russian Mathematical Surveys 32.6 (1977): 1-65.
[3] Danilov, V., and S. Nagaitsev. "Nonlinear accelerator lattices with one and two analytic invariants." Physical Review Special Topics-Accelerators and Beams 13.8 (2010): 084002.
[4] Nagaitsev, S., et al. "Design and Simulation of IOTA-a Novel Concept of Integrable Optics Test Accelerator." arXiv preprint arXiv:1301.7032 (2013).
[5] Valishev, A., et al. "Beam physics of integrable optics test accelerator at Fermilab." 2012 International Particle Accelerator Conference. 2012.
[6] Shiltsev, Vladimir, et al. "Tevatron electron lenses: Design and operation." Physical Review Special Topics-Accelerators and Beams 11.10 (2008): 103501.
[7] Nagaitsev, S., et al. "Design and Simulation of IOTA-a Novel Concept of Integrable Optics Test Accelerator." arXiv preprint arXiv:1301.7032 (2013).
[8] McMillan, Edwin M. "A problem in the stability of periodic systems." Topics in modern physics, a tribute to EV Condon(1971): 219-244.
[9] Danilov, V. V., and E. A. Perevedentsev. "Two examples of integrable systems with round colliding beams." Particle Accelerator Conference, 1997. Proceedings of the 1997. Vol. 2. IEEE, 1997.
[10] Laskar, Jacques. "The chaotic motion of the solar system: A numerical estimate of the size of the chaotic zones." Icarus88.2 (1990): 266-291.