EXPLORING STORAGE RING LATTICES: INDUS-1 & INDUS-2

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Abstract

Storage ring lattice design is a highly constrained multi-objective optimization problem. The objectives can include tunes, lattice functions, momentum compaction factor or derived quantities like emittance, brightness etc. with linear stability of the lattice. Generally, the solutions are found through trial and error and it is not clear that the solutions are close to the optimal. A technique called GLASS (GLobal scan of All Stable Settings) is used which allows the rapid scan and find all possible stable modes then characterize their associated properties from the settings that may be of interest. In this paper, we illustrate how the GLASS technique gives a global and comprehensive vision of the capabilities of the lattice. It gives the lattice designer clear guidance as to where to look for interesting operational points. It generates the databank and can be browsed for the desired properties. We demonstrate the technique by taking example of Indus-1 and Indus-2 lattices.

INTRODUCTION

In storage ring one wants to adjust the lattice settings to obtain certain beam properties or a combination of properties such as low emittance (ε_x), small momentum compaction(α_c), certain dispersion function(η_x), horizontal beta function(β_x) at injection straight, small beam sizes and high brightness. Finding the required settings, which provides the desired properties, is not straight forward. Traditionally, the approach is to first find stable solutions that approximately meet the desired properties and then perform fine optimization around it. This approach has several weaknesses. In particular, it can be slow and does not guarantee that one has obtained an optimal solution. What is desirable is to be able to obtain a global understanding or view of the lattice to rapidly guide one towards optimal solutions. For very simple lattices such as a focus/defocus cell like Indus-1, it is possible to analytically determine the entire linear stability region—the so-called necktie diagram. For somewhat more advanced lattice like Double Bend Achromat (DBA) of Indus-2, scans of quadrupole settings have been done to get a wide ranging feel for the different stability regions. With the present computer speed, global scans have become more practical. In this paper, we perform wide scans technique, which identifies stable regions, computes lattice properties, and provides a global view of the lattice. The technique used to search for different operational modes is straightforward and powerful.

In this technique, instead of trying to fit the lattice to find specific properties, we go by steps: (i) scan all possible quadrupole settings; (ii) find all stable settings; (iii) compute properties of all stable settings; (iv) filter by property settings of interest. At the end of the process one has a database with all possible solutions and associated beam properties. Then, by querying the database against certain properties, it is possible to find any lattice settings that satisfy the properties. In addition, the data can be viewed such as to give a global understanding of the lattice. This technique is called GLobal scan of All Stable Settings or GLASS [1]. We use this technique to explore the Indus-1 and Indus-2 storage ring lattices.

INDUS-1 STORAGE RING LATTICE

Indus-1[2] is a 0.45GeV storage ring consisting of 4 superperiods. Each superperiod accommodates 2 families of quadruples—QF and QD. Indus-1 is presently set to operate at the tunes [ν_x, ν_z]: [1.61, 1.47] with beam emittance ε_x =192[nm.rad] and momentum compaction α_c=0.286. Here we explore the operational regions of Indus-1 with GLASS.

The first step is to scan the quadrupole families over a wide range covered by the operational capabilities of power supplies. The magnet strengths k_{QF} and k_{QD} are scanned over 400 settings ranging between -5 to 5[m^{-2}]. There are 1.6×10^5 combinations scanned and for each combination, the 4D linear transfer matrix is computed and stability condition is checked, by requiring the *trace* of the 2x2 transfer matrix in both the horizontal and vertical planes to be less than 2. The computation is done using the code AT [3]. This process is a little time consuming but only needs to be done once. Out of the scanned settings ~50,000 solutions were stable. Each stable setting is recorded and plotted in Figure (1a) in k-space. There are 4 distinct regions where stable solutions exist. Indus-1 is operating in region 2. The emittance range from low value 58 to high value 10^6 [nm.rad] and α_c ranges from 0.04 to ~100. It is important to note that the constraint of linear stability is a necessary but not sufficient condition for operation of storage ring. Not all scanned lattices found are feasible. The GLASS results contain all possible practical results as well as some impractical results.

The next step in the GLASS process is to compute relevant properties for each of these stable settings from global database. For example, one can search for all solutions where ε_x is small or α_c is small. This requires no fitting or guess work. All possible solutions are found. Querying the database for multiple properties is effective for rapidly locating optimal solutions to a broad set of requirements. In Figure (1b) we plot the ε_x up to 500[nm.rad] for stable lattice settings in tune space at various α_c values. Figure (1c) shows ε_x with quadrupole

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strengths for stable lattices at various α_c values. There are lattices that support small ε_x (58nmrad) value or lattices with small α_c (0.04) value. In fact, it is possible to get both small ε_x (62nmrad) and small α_c (0.13).

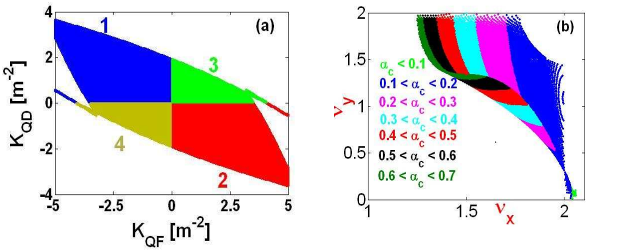

Figure 1: a) All scanned stable lattices of Indus-1 in k-space, b) stable lattices in tune space up to ε_x of 500[nm.rad] and α_c up to 0.7.

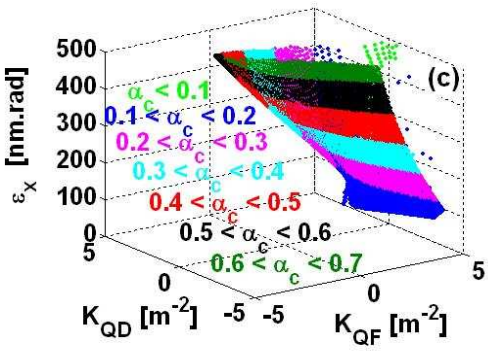

Figure 1c: Emittance with stable quadrupole strength settings at different α_c in Indus-1.

INDUS-2 STORAGE RING LATTICE

Indus-2[4] is a 2.5GeV storage ring with DBA lattice consisting of 8 superperiods. Each superperiod consists of 5 families of the quadruples - Q1D, Q2F, Q3D, Q4F and Q5D. The Indus-2 presently operates at tunes [ν_x, ν_z]: [9.3; 6.2] with ε_x=120[nm.rad] at 2.5GeV and $\alpha_c = 7.3 \times 10^{-3}$. The quadrupole magnet strengths are scanned in the range: -2.15 to 2.15[m^{-2}], which is within operational capabilities of power supplies. The constraints: max (β_x & β_y) <25[m] and max (η_x)<1.5[m] are also imposed to get more practical solutions. There are 3.5x10^9 combinations scanned and ~3.5x10^6 are found stable. All stable settings are saved in the global database. All scanned stable settings in tune space in a superperiod are shown in Figure (2a) (colors show the squared grid of dimensions 0.5x0.5 in tune). The beam emittance ε_x with α_c are shown in Figure (2b). The values of ε_x range from low value 17 to large value 2x10^4 [nm.rad] and α_c in the range: -0.015 to 0.045. This shows the full range capability of Indus-2 lattice. Table-1 lists some of the lattice settings for desired ε_x and α_c selected from the scanned database for Indus-2.

Using GLASS technique, a global database is generated for linear stable lattices of Indus-1 and Indus-2. Large number of parameters like tunes, chromaticities, dispersion function at injection, maximum dispersion function, beta function at injection, maximum beta function, beam emittance, momentum compaction factor etc. are recorded for all stable lattice settings. By searching a global database, lattice of desired properties can be chosen and taken for further studies for its operational possibilities.

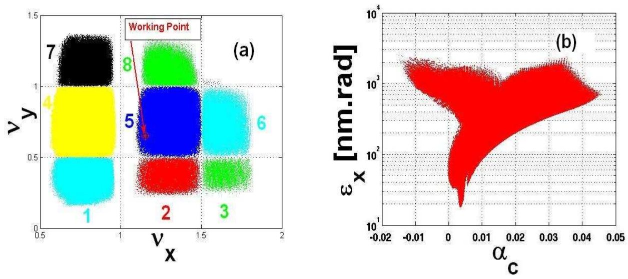

Figure 2: a) Stable setting in tune space and b) emittnace with momentum compaction factor for all stable settings of Indus-2 lattice.

Table 1: Set of quadrupole strengths for few Indus-2 lattices. Emittance (ε_x) is in units of [nm.rad].

Q1D [m^{-2}]	Q2F [m^{-2}]	Q3D [m^{-2}]	Q4F [m^{-2}]	Q5D [m^{-2}]	Tunes	α_c	ε_x
-0.79	1.55	-1.71	1.81	-1.42	[9.30, 6.20]	7.3e-3	120
-1.70	1.84	-1.76	1.88	-1.06	[9.32, 6.22]	4.3e-3	25
-1.95	1.90	-1.65	2.05	-1.15	[10.2, 5.47]	3.4e-3	18
-1.30	1.70	-1.10	-0.80	1.50	[9.24, 6.15]	1e-4	78
-1.45	1.80	-1.20	-0.55	1.45	[10.06,5.06]	6e-6	50

CONCLUSION

The GLASS technique allows to explore all possible linear stable solutions and associated properties for a given lattices. The technique is applied for Indus-1 and Indus-2 lattices and a global database is generated for linear stable lattices. It provides the full range operational capability of the lattice. A stable lattice of interest can be chosen by browsing the global database to further study for its operational possibilities.

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