EXPLORING THE LIMITS OF THE ALS TRIPLE BEND LATTICE *

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Abstract

The triple bend achromat cell of the ALS has been shown to be very flexible and compact. It has been operated in a low emittance mode and a low momentum compaction mode. In fact the lattice can be operated in a large range of different stable modes. Until recently most of these recently discovered modes had not been explored or even known about. Many of these modes have potentially attractive features as compared with the present operational mode. In this paper we take a step back and look at the general stability limits of the lattice. We employ a technique we call GLASS that allows us to rapidly scan and find all possible stable modes and then characterize their associated properties. In this paper we illustrate how the GLASS technique gives a global and comprehensive vision of the capabilities of the lattice.

MOTIVATION

Let's assume that one has a storage ring and wants to adjust the lattice settings to obtain certain properties such as low emittance or a small momentum compaction, etc. Determining how to adjust the lattice to achieve certain properties is not a straight forward process. The process is actually blind and involves a lot of trial and error. In many ways it is an art which is aided by the instincts and experience of the practitioner.

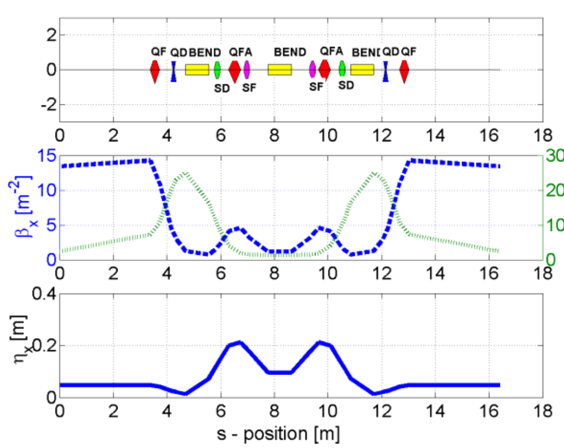

Figure 1. Lattice of one of 12 ALS sectors and associated optical functions in the nominal operational mode

This is even true for a lattice structure that is a simple and well studied as the triple bend structure (TBA) of the Advanced Light Source (ALS) – see Fig. 1. The ALS consists of 12 sectors. The basic ALS sector is a mirror symmetric TBA structure consisting of 3 families of quadruples – QF, QD, and QFA. The present setting of the storage ring of ALS nominally operates at tunes (Nux, Nuy) = (14.25, 9.20) and Eta=0.06 [m] (dispersion at the center of the long straight sections) with the emittance of 6.8E-9 [m*rad] at 1.9 [GeV] (See Fig. 1).

The lattice has been operated for users in some other modes – zero dispersion in the straights and at a vertical tune of 8.2 where the vertical beta function was larger. In special operation shifts the lattice has also been operated in a large emittance zero momentum compaction mode. Also recent studies have shown that it is possible to significantly reduce the emittance from our present operational mode [1].

This leads us to the question of where there are still other modes that would be supported by the lattice that have yet to be found. For instance, could one operate with a lattice with a small emittance and a small beta function in the straights? Or are there modes that have both a small emittance and a small momentum compaction factor? To answer these questions and others we developed a technique that takes the guess work out of the optimization process, making it more transparent.

GLASS TECHNIQUE

The technique that we use to search for different operational modes is straightforward and powerful. Yet, to our knowledge this approach has not been used before.

Instead of trying to fit the lattice to find specific properties, we followed the following steps

- Scan all possible quadrupole settings
- Find all stable settings
- Compute properties of all stable settings
- Filter by property all settings that may be of interest

At the end of the process one has a data base with all possible solutions and associated properties. Then, by querying the database against certain properties, it is possible to find any and all lattice settings that satisfy the properties. In addition, the data can be viewed such as to give a global understanding of the lattice. We call this technique GLobal scan of All Stable Settings or GLASS which gives a global view of the lattice.

At first, it seems impractical to scan all possible lattice settings. But in fact for simple lattices, it is not only possible but also very practical. We illustrate this for the example of an ALS sector.

EXAMPLE - ALS

The first step in the GLASS process is to scan the quadrupole families. For all 3 quadrupole families, the

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magnet strengths kQF, kQD, and kQFA are scanned over 1000 settings ranging between k = $-10m^{-2}$ and $10m^{-2}$. All together, there are 1 billion combinations. For each of these combinations the 4D linear transfer matrix is computed and determined to be stable [2]. The total time to scan all possible settings is less than one day. This process only needs to be done once.

Each stable setting is recorded and plotted in Fig 2. As can be seen, there are many (> 10) distinct regions where stable solutions exist. Of the billion initial combinations approximately 1 million were stable. In the case of the ALS, most of these regions are far from any that had been previously explored or even known about.

The next step was to compute relevant properties for each of these stable settings. For instance, one can compute the tunes, momentum compaction, emittance, dispersion, beamsizes at the source points, etc, whatever may be of interest. This takes very little time (minutes).

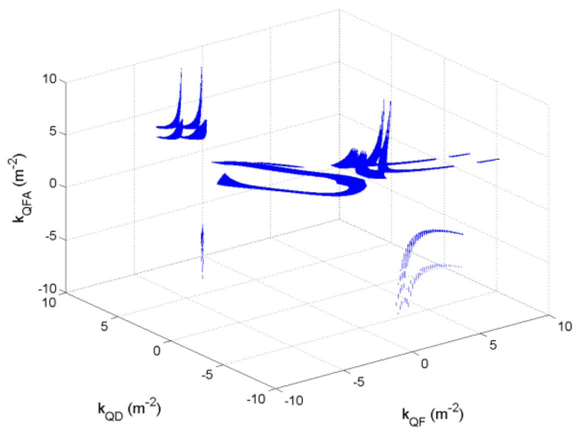

Figure 2. All linear stable solutions in k space

From this data one can now query the data base against different properties. For instance, we can search for all solutions where the emittance is small (Fig 3 top). Or one can look for all solutions where the momentum compaction is small (Fig 3 bottom). This requires no fitting or guess work and all possible solutions are found. In fact, with this process, a previously unknown lattice mode was discovered that had simultaneously small emittance and small momentum compaction.

Querying the database for multiple properties is very useful. For instance, one could search for lattices that have a low emittance lattice that a small horizontal betafunction in the straights, a large vertical beta function in the arcs, etc. The result is fast and comprehensive. This makes GLASS very powerful.

In addition, we can use the computed properties to try to further understand the stability regions. In Fig. 4 the tunes of all stable lattices are plotted. There are stable solutions scanning a large range – 0.5 to 2 horizontally and 0 to 2 vertically. The solutions are plotted in color. This color scheme is then mapped back onto the k plot (See Fig 5).

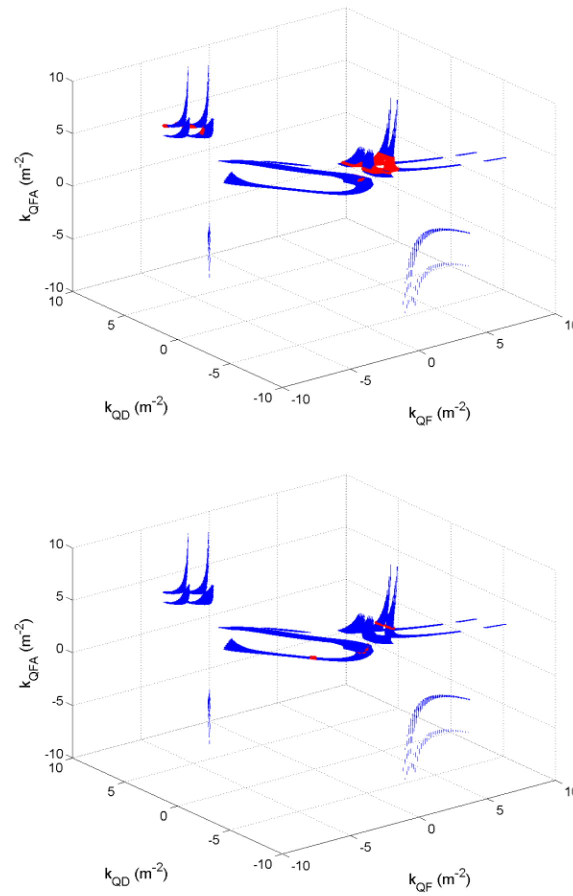

Figure 3. All solutions in red with small emittance (<10 nmrad) top and with small momentum compaction ($|\alpha_1|<0.00001$) bottom

One sees that the distinct regions in Fig 1 can be separated by tune. For the 4 tune regions spanning horizontal tunes of 0.5 to 2 and vertical tunes of 0 to 2 one has 8 regions in k space. When looking at the solution one sees that this corresponds to switching the polarity of the QF/QD doublet. The nominal tune of the ALS cell is (1.19, 0.77) which is in the right yellow region.

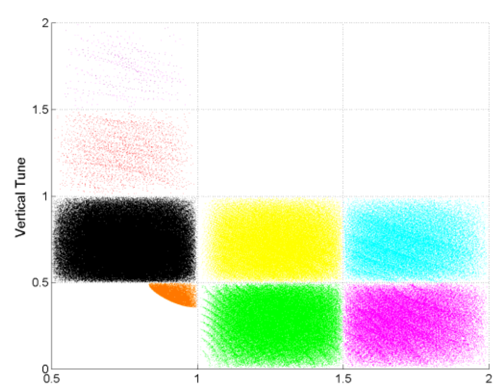

Figure 4. Tune of all stable solutions

Let's first look at the green, blue, magenta and yellow regions on the right. For the most part, these are low emittance modes. However, there are distinct differences in the Twiss and dispersion parameters. The nominal lattice (See Fig. 1) is located in the yellow region. A lattice located in magenta region is plotted in Fig. 6. The green and yellow regions have large horizontal beta functions in the straight section whereas the blue and magenta do not. In the blue and yellow regions, the vertical beta function is a minimum in the center bend whereas it is a maximum in the green and magenta regions. Therefore, depending on what beamsize or divergence one would like in the straights or arcs, this would help to guide one to the proper region.

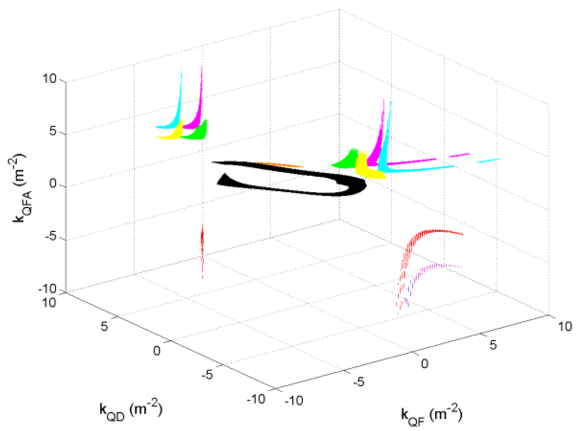

Figure 5. All stable solutions in k-space mapped to tunes.

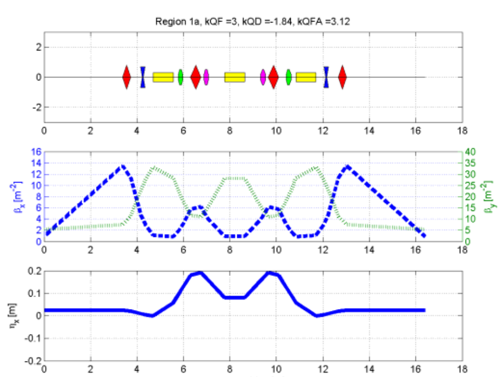

Figure 6. Lattice in magenta region with horizontal tune > 18 and vertical tune < 6

Another feature of some lattices in the magenta and blue regions are that the momentum compaction is small and can be made negative with the dispersion being negative in the outer bends and positive in the inner bends. This region was previously undiscovered and has isochronous lattices with very attractive properties (such as low emittance.)

Next let's examine the black region. One feature of some lattices in this region is that it is also possible to operate with a low or even negative momentum compaction region. This was in fact known [3]. As one can see from the lattice plotted in Fig. 7, it is very different from the lattice plotted in Fig. 6. The dispersion is positive in the outer bends and negative in the inner one. The GLASS analysis also revealed some very curious effects about this region. One such curiosity is that in the black region it is possible to turn off either the QFA or both the QF and QD magnets and still be stable! This fact that is in principle probably of little practical interest is nevertheless a very counter intuitive result.

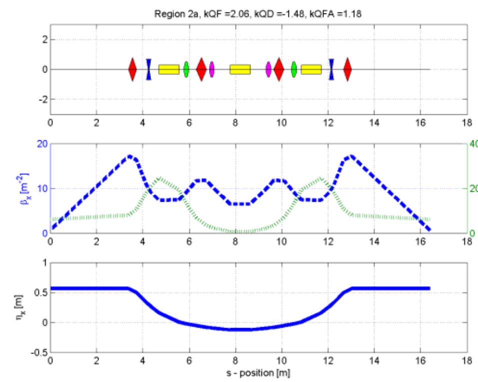

Figure 7. Zero momentum compaction lattice in the black region.

CONCLUSION

A newly developed technique GLASS allows one to see all possible linear stable solutions and associated properties for a given simple lattice. It has been shown that, by using GLASS, one has uncovered many interesting and unknown stability regions. The number of regions is much more extensive than we had thought. (Of the > 10 regions we had only known of 2.) In a sense, GLASS functions as a lattice observatory clearly displaying all possibilities.

In this paper, we present only three of the many stable regions were presented here. Similar to those three, all other stable regions have distinctive features which may be of interest.

The power of the GLASS technique is that it is very fast and comprehensive. There is no fitting involved. It gives the lattice designer clear guidance as to where to look for interesting operational points. Of course, GLASS only evaluates the linear stability so more studies need to be done to look at the practical nature of a given lattice.

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