APPLICATION OF THE FREQUENCY MAP ANALYSIS TO THE NEW LATTICE OF THE SOLEIL PROJECT*

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Abstract

The SOLEIL lattice has been modified in order to increase the number of straight sections for Insertion Devices. The linear and non-linear optics have been optimised and satisfy as good results as in the APD study[1]. A deep investigation of the dynamics was performed for two different working points using the Frequency Map Analysis. This technique enables a better understanding of the non-linear beam dynamics and the inner complex structure of the dynamic aperture which is essential to choose the best working point.

1 INTRODUCTION

In order to reach the best performances in terms of lower emittance and higher brilliance, third generation light sources are more and more optimised on stronger focusing lattices. This involves the use of high strength magnetic fields which unfortunately excite numerous resonances and so alter the global dynamics of the particles. The result is obviously lower dynamic aperture and energy acceptance which limit consequently the beam lifetime. The difficulty remains in how to determine these dangerous resonances and their amplitudes. The rule in the design of lattices is to avoid lower order resonances and the tools in the optimisation codes allow to minimise only the third order ones which are thought to be the most dangerous.

The Frequency Map Analysis[1] (FMA) is a numerical method which allows to identify naturally these resonances and to have an idea about their width [2]. In few words, the FMA constructs numerically a map following this scheme[3,4]:

In the 6-dimensional (x, p_x, z, p_z, s, δ) space representation of a particle in a ring, one can fix the momentum coordinates to 0 ($p_x = p_z = 0$) and for a given initial position condition (x_0, z_0), the phase trajectory of the particle is numerically integrated. At a longitude s (generally s = 0), the discrete trajectory ($x^k(t)$, $z^k(t)$, $p_x^k(t)$, $p_z^k(t)$) is kept at each turn k during a certain time of integration T. Using the FMA algorithm, the fundamental frequencies[2] (ν_x , ν_z) are calculated. This procedure is repeated for a grid of initial conditions covering for example the physical aperture.

In fact, the trajectory of the particle is integrated over two consecutive time intervals [0, T]. In each interval, one couple (ν_{x1} , ν_{z1}), (ν_{x2} , ν_{z2}) is calculated. If these couples are different, the orbit diffuses. This time dependence tunes calculation gives an important information about the long term stability of the system. Another interesting feature of the FMA is the fact that it provides the inner structure of the dynamic aperture.

2 RESULTS AND DISCUSSION

Applying the construction scheme described above, frequency maps (FM) and dynamic apertures have been computed for two different working points (ν_x , ν_z) of the machine: (18.29, 10.26) and (18.27 , 10.18). The study concerns only the on-momentum particles and the perfect lattice (4-fold periodicity) of SOLEIL. The optics were optimised linearly and non-linearly with 10 sextupoles families and using the BETA code[1, 5]. Maps calculation has been performed using DESPOT tracking code[6] and integrating the particle trajectory over 2×1000 turns. This is consistent with the fact that the damping due to synchrotron radiation (τ_s = 3.45ms ≡ 29000 turns), has been ignored. In this study, the diffusion information has not been exploited.

2.1 Optics 1 : (18.29 , 10.26)

This optics has been optimised constraining the horizontal tune shift with amplitude to stay beyond the 3[rd] order resonance ($3\nu_x = 55$), see Fig. 1.

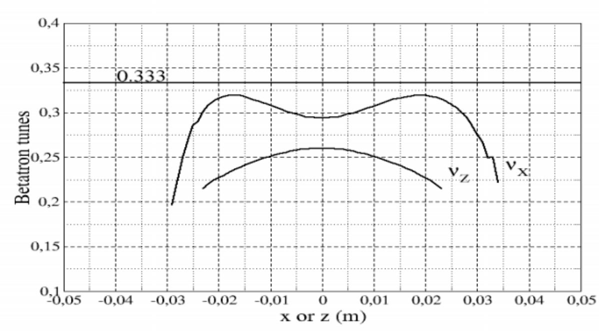

Figure 1: Tunes shift with amplitude for the ideal optics1.

[1] The FMA combines a tracking code and a numerical algorithm in order to obtain a frequency domain representation of the particle dynamics.

[2] The longitudinal motion is neglected in this study.

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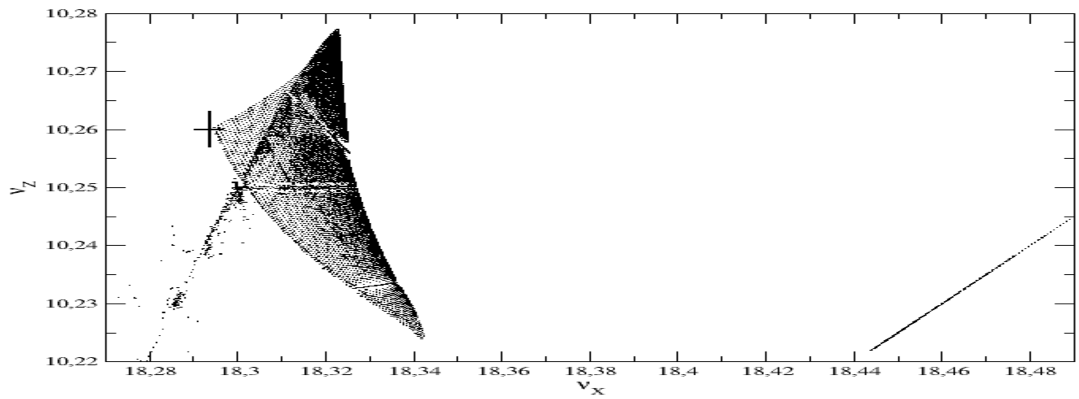

Figure 2: The frequency map computed for the ideal optics (18.29 , 10.26) at the entrance of the machine (β_x = 10 m).

Figure 2 shows the FM calculated for this tuning. The cross indicates the position of the working point. The FM is folded. Although this effect and its consequences on the dynamics are not studied here, we know from theoretical studies that this can lead to strong instabilities as the torsion becomes indefinite after the fold[7]. The upper border of the FM (respect the lower border) corresponds to the horizontal (respect vertical) tune shift with horizontal (respect vertical) amplitude.

The FM reveals a relatively stable dynamics. Nevertheless, several resonances which perturb more or less the dynamics are identified (see Fig. 3). Table 1 resumes these resonances up to 7th order.

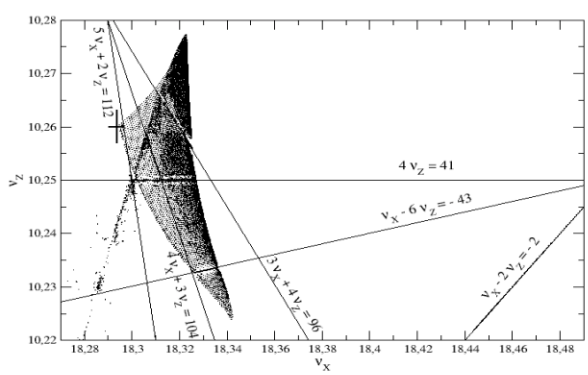

Figure 3: Identification of resonances on the FM for the ideal optics (18.29 , 10.26).

In order to see the real dangerousness of these resonances and at which amplitudes they will act, one have to exploit the diffusion information.

One can remark that these resonances are excited even if the machine is ideal but one have to be aware of the fact that the real machine is not perfect. Magnetic errors from magnets and Insertion Devises destroy the periodicity and excite the resonances with larger amplitude than appearing in an ideal machine. That's why one need to consider the possible effect of high order resonances which can be excited on the real machine. The dynamic aperture (Fig. 4) seems regular and large, its dimensions are $[-27mm, 32mm]_{z=0} \times [0, 26mm]_{x=0}$. We can also see the presence of an island which can reduce the horizontal dimension to only $[-20mm, 32mm]_{z=0}$.

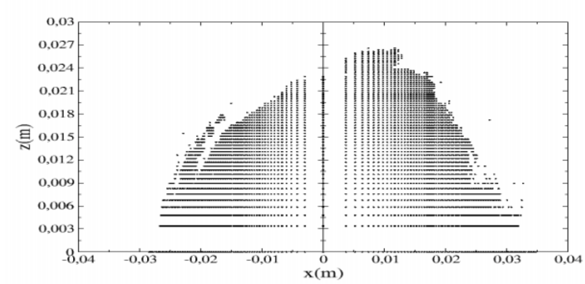

Figure 4: Dynamic aperture calculated for the ideal optics (18.29 , 10.26) at the entrance of the machine (β_x = 10 m).

2.2 Optics 2 : (18.27 , 10.18)

For this second optics, the working point is moving down to (18.27 , 10.18). This has been optimised constraining the tunes shift with amplitude to be as flat as possible (see Fig. 5). Figure 6 represents the FM calculated for this tuning.

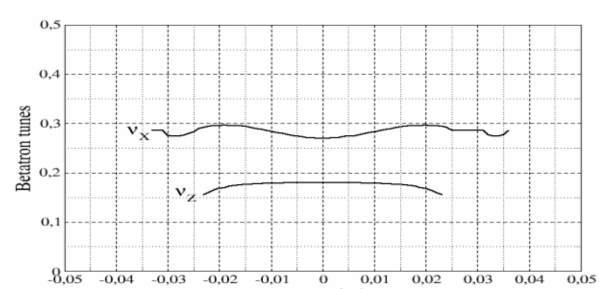

Figure 5: Tunes shift with amplitude for the ideal optics2.

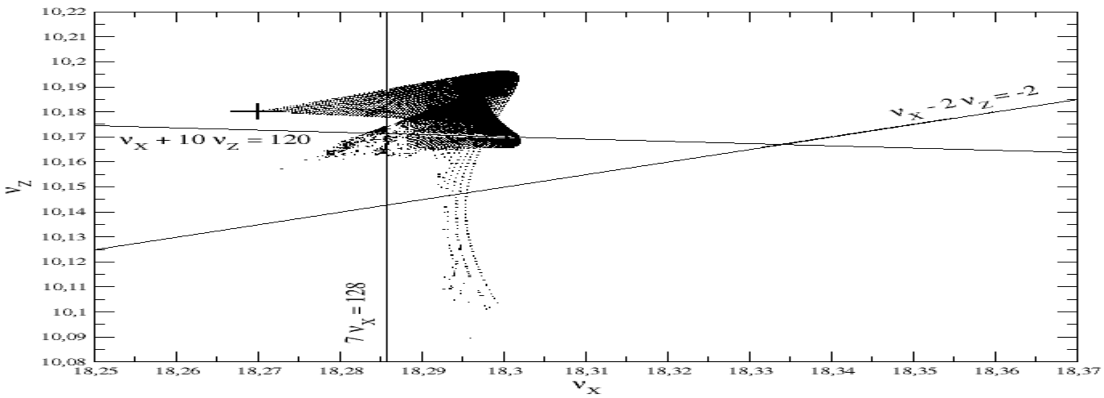

Figure 6: The frequency map computed for the ideal optics (18.27 , 10.18) at the entrance of the machine ($\beta_x = 10$ m).

The dynamics seems regular and fewer resonances than previously are identified (see Fig. 6).These resonances are contained in Table 1.

The dynamics shows a single low order resonance $\nu_x - 2\nu_z = -2$ and two high order resonances (7th and 11th orders) which intersect.

The frequency map is now folded twice on itself, which allows to recover a definite torsion after the second fold, and its extension is shorter than that of the previous studied optics.

The dynamic aperture (see Fig. 7) is regular, almost symmetric and not much different in size than the previous one $[-31\text{mm}, 28\text{mm}]_{z=0} \times [0, 23\text{mm}]_{x=0}$. There is also an island which can reduce the horizontal dimension to only $[-28\text{mm}, 28\text{mm}]_{z=0}$.

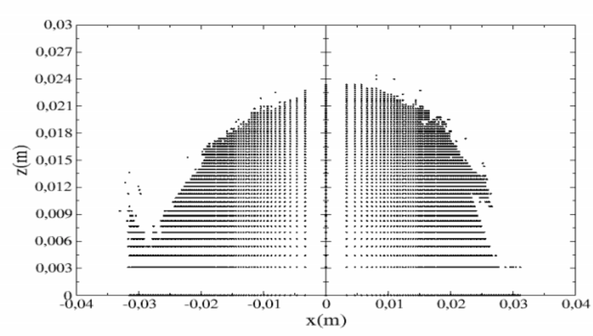

Figure 7: Dynamic aperture calculated for the ideal optics (18.29 , 10.26) at the entrance of the machine ($\beta_x = 10$ m).

Ideal optics (18.29,10.26)	Ideal optics (18.27,10.18)
$\nu_x - 2\nu_z = -2$	$\nu_x - 2\nu_z = -2$
$3\nu_x + 4\nu_z = 96$	$7\nu_x = 128$
$4\nu_z = 41$	$\nu_x + 10\nu_z = 120$
$\nu_x - 6\nu_z = -43$	
$4\nu_x + 3\nu_z = 104$	
$5\nu_x + 2\nu_z = 112$	

Table 1: Identified resonances for the two studied optics.

Comparing the two studied optics, one can say that the dynamics revealed by the second optics seems more stable with less perturbing resonances than the first one.

3 CONCLUSION

A powerful tool (FMA) for investigating the stability of on-momentum particles in two different optics of SOLEIL machine has been used. The studied optics at (18.29 , 10.26) and (18.27 , 10.18) are both ideal. The purpose is to explore the most stable region for the circulating particles and so choose the best working point. It is important to see how much the behaviour of a frequency map is sensitive to the change of the sextupoles forces. Quantitatively, the sextupoles forces are different of 0.6% to 28% and the corresponding dynamics are quite different, even if the dynamic apertures are almost similar.

Basing on this limited study, the second optics at (18.27 , 10.18) seems more stable with few troubling resonances. There is of course much more informations to deduce when exploiting the diffusion and simulating a more realistic machine by including realistic errors. We need to explore further the influence of the folding of the FM. This study has also to be completed for the off-momentum particles. Moreover, the influence of radiation damping and quantum excitation is necessary to understand.

4 REFERENCES

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