LOW MOMENTUM COMPACTION OPTICS FOR ELETTRA

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Abstract

The DBA optics lattice of Elettra, the third generation Italian light source, is closer to DBA minimum emittance achromat condition than any other similar lattice. At the same time, although the lattice is also optimized for large acceptance, it is very inflexible to any changes like the reduction of the momentum compaction (very desirable to the Infra-Red and SR-FEL beam lines). Nevertheless a solution has been found and consists in abandoning the achromat condition and reversing the polarity of some quadrupole and sextupole families. This special optics and its applications to Elettra are presented and discussed.

INTRODUCTION

Elettra operates for the large majority of its users at 2 and 2.4 GeV. However a small subset of users is interested in short bunches i.e. of the order of a few ps that in the past were obtained using the capacity of the storage ring to reach energies as low as 0.75 GeV. This way experiments in the THz region were performed. The advantage of this method is that one is not beam current limited and by using an external perturbation, strong pulsed but stable bursts of THz radiation can be produced [1]. Another way to produce short bunches is by acting on the optics lattice in order to decrease the momentum compaction factor α which scales with the bunch length σ as $\sim\sqrt{\alpha}$

Since the momentum compaction of Elettra is 1.6 10^{-3} and its natural bunch length at 2 GeV is 18 ps, in order to arrive at about 1 ps the momentum compaction should be decreased by 2 orders of magnitude, while operating at 1 GeV where the bunch length is only 6 ps to arrive at 1 ps the momentum compaction should be only 36 times smaller i.e. about 4 10^{-5} .

Nevertheless although the Elettra optics is highly optimised and performing for its nominal configuration, it is completely inflexible to any changes; practically there is no way to change the momentum compaction while keeping the other features. The solution found that permits this feature will be discussed after a short presentation of the nominal lattice.

THE NOMINAL LATTICE OF ELETTRA

Elettra has adopted [2] the double bend achromat (DBA) lattice arranged in an optimal way for large momentum aperture, low coupling, low sextupole strengths and low emittance. To achieve all that the structure uses three quadrupole doublets (Q1,Q2,Q3) in the straight sections and two focusing (QF) and one defocusing quadrupole (QD) in the arcs between the bends. This allows a lower coupling of horizontal and vertical beta values at the sextupole positions and an increase in the dispersion value between the dipoles which again reduces the strength of the sextupoles. Apart for the advantage for chromaticity corrections this structure is also necessary in order to achieve the minimum emittance. In general the horizontal emittance is given (see for example [3]) by:

$$\varepsilon_{x0}[nmrad] = 31.64\frac{K}{J_x}[E(GeV)]^2\varphi^3$$

where K is a value that depends upon the magnetic structure and is given by the distribution of the beta and dispersion functions in the bending magnets, Jx is horizontal partition number while ϕ is the deflection angle per magnet.

It is known that in order to minimize the emittance at least two focusing quads separated by a large drift are needed and to this Elettra has an additional defocusing qudrupole in the middle that makes the phase advance between the bending magnets roughly equal to 2π reducing thus the K-value. This feature has been combined with a gradient in the dipoles in order to prevent the vertical beta function becoming very large. In addition increases the horizontal damping partition number, J_x=1.3 which adds to the emittance reduction.

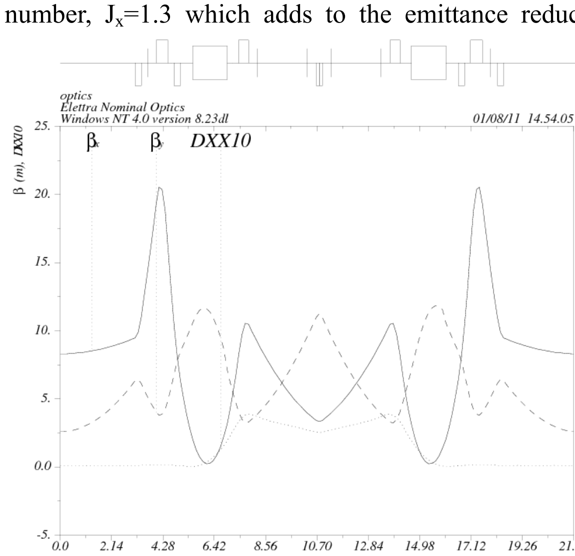

Figure 1: Elettra nominal optics with α_0=1.6 10^{-3}

The lowest practical K-value for a DBA structure is K=3 that would give for Elettra an emittance of 5.2 nm-rad at 2 GeV. The actual emittance however is slightly larger since it was preferred to keep the beta values small and the phase advance at its optimum working point (Qh=14.3, Qv=8.2), consequently the emittance of Elettra is 7.4 nm-rad corresponding to a K= 4.1 i.e. only a factor of 1.37 above the minimum. Thus ELETTRA operates almost at the minimum emittance achievable for a DBA lattice with dispersion free straight sections.

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In this lattice however it is impossible to reduce the momentum compaction while keeping the phase advance at its optimum working point. The momentum compaction can be reduced by increasing the strength of the focusing doublet between the dipoles at the cost of abandoning the achromat condition; however when one tries to bring the phase advance at its previous value the momentum compaction returns to its original value. This behaviour can be attributed to the defocusing quadrupole in the middle of the arc which provides additional vertical focusing keeping the vertical beta values and the phase advance under control but renders "rigid" the dispersion function.

THE LOW ALPHA LATTICE

To gain control of the momentum compaction and at the same time not bring major changes in the lattice is by changing the polarity of the defocusing quadrupole QD (12 magnets powered by one power supply) and switch off the first outmost doublet (Q1) of the defocusing quadrupoles creating thus non zero dispersion in the straights; note that modern machines have abandoned the zero dispersion condition in order to gain flexibility and further emittance reduction. The reversed polarity quadrupole, focusing in this new optics, is used to control the momentum compaction and the remaining doublets to keep the phase advance at the optimal value.

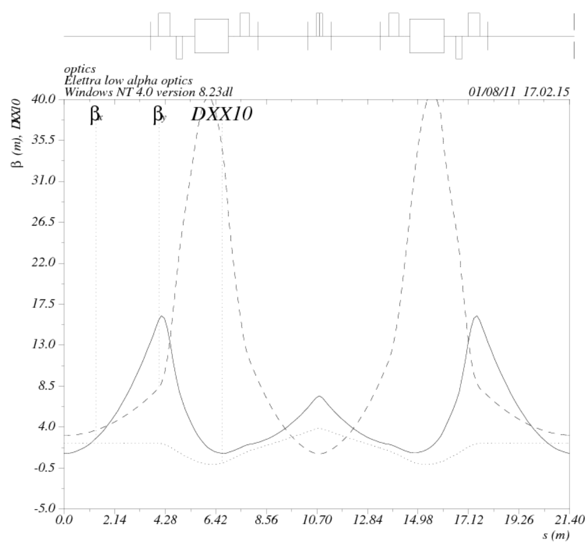

Figure 2: Low momentum compaction optics, α_0=3 10^{-7}

At that value of momentum compaction (i.e. almost 4 orders of magnitude lower that the nominal) the emittance becomes 14 nm-rad i.e. the double of its nominal optics. It is interesting to see that by slightly changing the QD strength one obtains full control of the momentum compaction while the emittance remains < 15 nm-rad. In the next table 1 the momentum compaction and the emittance along with the quadrupole strength, keeping the tunes at their nominal values (14.3 e 8.2), is shown. It is interesting to note that there are also solutions for negative momentum compaction (i.e. below transition).

Table 1: Momentum Compaction and Emittance for various Settings of the QD Strength

QD strength	Momentum compaction	Emittance (nmrad)
1.8	-1.00E-04	
1.75	-5.00E-05	
1.715	-7.00E-07	
1.7145	3.00E-07	14
1.7125	3.00E-06	7.6
1.695	3.00E-05	7.2
1.6	2.00E-04	5.7
1.31	1.60E-03	14

Note the minimum emittance solution for α=2 10^{-4} in a non zero dispersion lattice.

THE HIGHER ORDERS OF MOMENTUM COMPACTION

It is well known that in general optics programs such as MAD [4] provide the total momentum compaction α_p and not its components. In general α_p can be expanded as:

$$\alpha_p \equiv \frac{\Delta C/C}{\Delta p/p} \equiv -\frac{\Delta f/f}{\Delta p/p} = \alpha_0 + \alpha_1 \frac{\Delta p}{p} + \alpha_2 \left[\frac{\Delta p}{p}\right]^2 + \ldots$$

and in order to calibrate the optics program the nominal lattice has been used. In the next figure 3 measurements of synchrotron frequency for different optics settings (changing the QF excitation but correcting the tunes to the nominal value) versus the calculated momentum compaction for each one of the optics are shown.

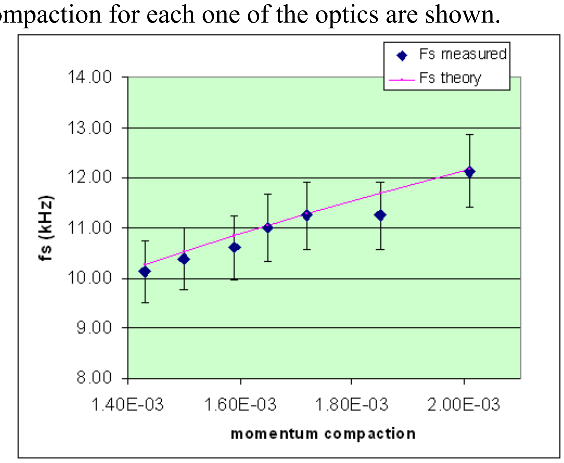

Figure 3: Measured synchrotron tune vs calculated momentum compaction for the nominal optics.

Since the model is in satisfactory agreement with the measurements, it is safe to use it for further analysis.

Table 2: Values of the first 3 Terms of the Momentum Compaction for Three Different optic Settings.

Optics	α_0	α_1	α_2
Nominal	1.55 10^{-3}	-1.26 10^{-4}	3.45 10^{-3}
Low alpha 1	2.16 10^{-4}	-2.39 10^{-3}	1.37 10^{-2}
Low alpha 2	2.22 10^{-5}	-3.43 10^{-3}	1.95 10^{-2}

In the next figure 4 the calculated relation of the momentum compaction versus of $\Delta p/p$ for the nominal and two cases of the low alpha optics are shown.

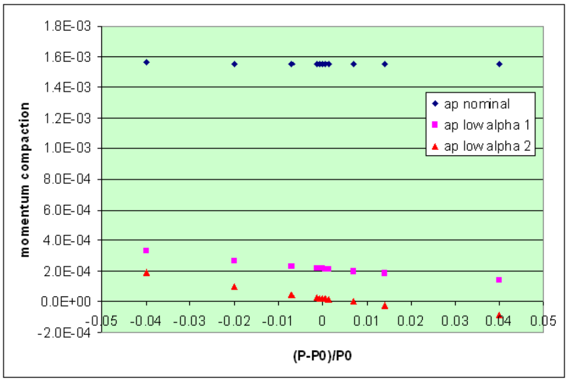

Figure 4: Momentum compaction versus Δp/p for the nominal and two cases of the low emittance optics.

To those data a quadratic fit was applied in order to obtain the firsts three orders of alpha, shown in table 2. As is well known the higher orders may increase when the zero order decreases. Higher order multipole magnets are needed to minimize those terms, for example an appropriate setting of sextupoles minimises α_1.

DISCUSSIONS

The low alpha optics certainly is not optimized as much as the nominal neither it is very important since it will never substitute the nominal optics. Its biggest drawback is the low beta values in the straight sections (1.1 m against 8.3 m of the nominal) which make injection difficult but not impossible. To this one the reduction of the dynamic aperture should also be considered as shown in the next figure 5.

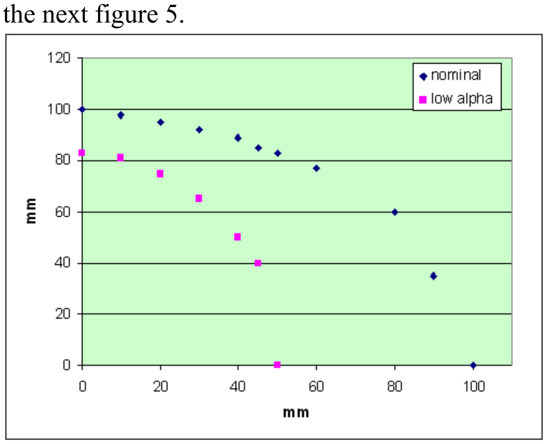

Figure 5: Dynamic aperture for the nominal and the low alpha (for a=3 10^{-5}) optics.

It is important to note that in order to achieve this rather large aperture the polarities of all three sextupole families had to be reversed, otherwise the aperture was collapsing to ±10 mm maximum in both x and y. Note that the present dynamic aperture at low alpha shown above is larger than the vacuum chamber dimensions.

As mentioned before the injection is difficult and the efficiency for the moment low (about 0.1 mA/s), while the transfer line is not well matched and the beam position monitor system does not deliver first turn / turn by turn measurements. Nevertheless it was possible to inject and store in the low alpha optics obtaining a good injection efficiency, enough current and a long lifetime (as shown in figure 6), for measurements.

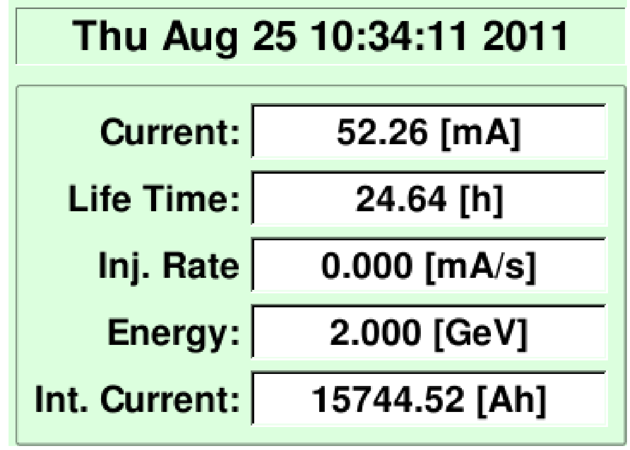

Figure 6: Current and lifetime with the low alpha optics.

With the above mentioned optics, a synchrotron frequency of 9.6 kHz was measured corresponding to a momentum compaction of 1.2 10^{-3}. It was possible to continue and store current for alphas reaching 5 10^{-4} albeit at a reduced efficiency without any major change of the injection settings. Below this value the machine has to be again re-optimized something that will be done in the near future.

At present it is quite cumbersome to prepare the machine for this experiment since four power supplies have to change polarity, this problem will soon be solved by installing commutating switches. Also the first turn / turn by turn measurements will soon be available while some work is currently under progress for the transfer line matching with the low momentum compaction optics. If injection at very low alpha proves to be impossible we intend to store some current at a larger alpha and then ramp the machine to the smaller alpha keeping tunes unchanged.

Finally all efforts to increase horizontal beta values in the straights result in increasing the momentum compaction. Seems that no common solution exists i.e. large horizontal betas and low momentum compaction while keeping the present magnet configuration.

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