# LATTICE STUDIES FOR THE TAC* AT 3.56 GeV

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## ABSTRACT

The minimum emittance is very important so that the brightness of the synchrotron radiation is a very high. The theoretical minimum emittance (TME) for a storage ring is given if both the horizontal betatron and the dispersion function have a minimum in the middle of the bending magnet and furthermore meet special values.
In most of the storage rings the emittance is s factor 2 to 5 higher as the TME-value.
The TME can be reached with a type of lattice composed of combined function bending magnets and a quadrupole doublet [1].
On the other hand, for isomagnetic three-or multiple-bend achromat lattices, the TME can only be attained if the length of the dipoles is $\phi$ a factor of $3^{1/3}$ longer than that of outer dipoles. Otherwise, the three- or multiple-bend achromat with equal length dipoles the TME can also be achieved by increasing the magnetic field middle dipoles by a factor of √3 larger than that of outer dipoles [2].

## INTRODUCTION

In recent years, electron storage rings have frequently have been used as light sources for research in atomic, molecular, condensed matter and solid state physics, chemistry, cell biology etc.
For many experiments, it is desirable to use high brightness light, which requires a small emittance of the beam.
Storage rings are build up with different magnet structures; FODO, DBA, TBA etc. The emittance of each structure can be expressed as:

$$\varepsilon_{xo} = f.\frac{1}{12\sqrt{15}}.C_q.\gamma^2.\frac{1}{J_x}.\theta^3 \quad (1)$$

Where $\theta$ is the deflection angle of the bending magnet, $f$ is a so called quality factor for each structure, $\gamma$ is the relativistic energy, $J_x$ is the horizontal partition factor and $C_q$= 3.84 x $10^{-13}$m.
Most of the synchrotron light sources uses DBA- or TBA structure.

The DBA or TBA lattice composed of $N_p$ periods withiso-magnetic field dipoles and

$$\theta_p = \frac{2\pi}{N_p} \quad (2)$$

bend angle per period, have a minimum emittance given by [3]

$$\varepsilon_{METBA} = C_q \frac{\gamma^2}{4\sqrt{15}} \frac{\theta_p^3}{J_x} \frac{1}{40.707} \quad (3)$$

$$\varepsilon_{MEDBA} = C_q \frac{\gamma^2}{4\sqrt{15}} \frac{\theta_p^3}{J_x} \frac{1}{8} \quad (4)$$

## THE DBA LATTICE

For the TAC at 3.56 GeV [4], the DBA lattice has been studied with a type of lattice composed of cf#-bending magnets and quadrupole doublet.
The unit cell with a defocussing bending magnet (cf-magnet) has a threefold advantage [5]:

1) The number of magnets per achromat is reduced;
2) The partition number $J_x$ is larger than 1 and thus reduces the emittance;
3) The length of the cell is small, therefore reducing the total circumference.

The only two free parameters which can be varied to minimize the emittance are the strength of the focusing quadrupole and the quadrupole strength of the bending magnet.

Table 1-Main parameters for quads, sextupoles and dipol magnet

| | Quadrupoles | Sextupoles | Dipol |
|---|---|---|---|
| Number | QF1/QF2/QF3 | SF1/SD1 | M1 |
| Length [mm] | 300/150/400 | 210/150 | 2200 |
| Strength[$1/m^2$,$1/m^3$,$1/m^2$] | 2.2/2.2/1.5 | 10.5/-7 | -0.39 |
| Curvature [1/m] | ---- | ---- | 0.06209 |
| Angle [rad] | ---- | ---- | 0.13659 |

*TAC; Turkish Accelerator Center Project, #cf; combined function

Table 2- Main parameters of the storage ring

| | |
|---|---|
| Achromatic structure | DBA |
| Nominal energy [GeV] | 3.56 |
| Superperiod | 23 |
| Circumference [m] | 301.76 |
| Main radius [m] | 48.03 |
| Harmonic number | 508 |
| Max. Beam Current [mA] | 400 |
| R. F. Frequency [MHz] | 504.69 |
| Energy loss/turn [keV] | 883.153 |
| Total radiation power [kW] | 353.261 |
| Energy spread [%] | 0.09468 |
| Momentum compaction factor | 0.001185 |
| Beam lifetime [h] | 34.468 |
| Horizontal emittance-$\varepsilon_x$ [nm.rad] | 3.066 |
| Vertical emittance-$\varepsilon_y$ [pm.rad] | 30.658 |
| Coupling [%] | 1 |
| Energy acceptance [%] | 6.958 |
| Betatron tunes† [$Q_x/Q_y$] | 20.645/5.86 |
| Natural chromaticities [$\xi_x/\xi_y$] | -37.019/-27.442 |
| Beta functions | |
| Horizontal (max/min)-[m] | 10.877/0.761 |
| Vertical (max/min)-[m] | 21.993/4.922 |
| Maximum dispersion [m] | 0.263 |
| Straight section [m/%] | 4.8/36.6 |

Around 36.6% of the circumference is devoted to straight sections(Fig. 3). Figure 1 shows the lattice functions in the unit cell of the storage ring.

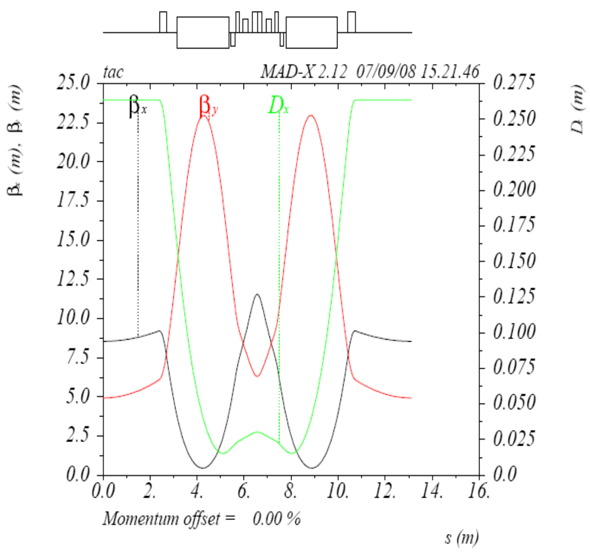


Fig. 1: Lattice functions for 23 period DBA lattices.

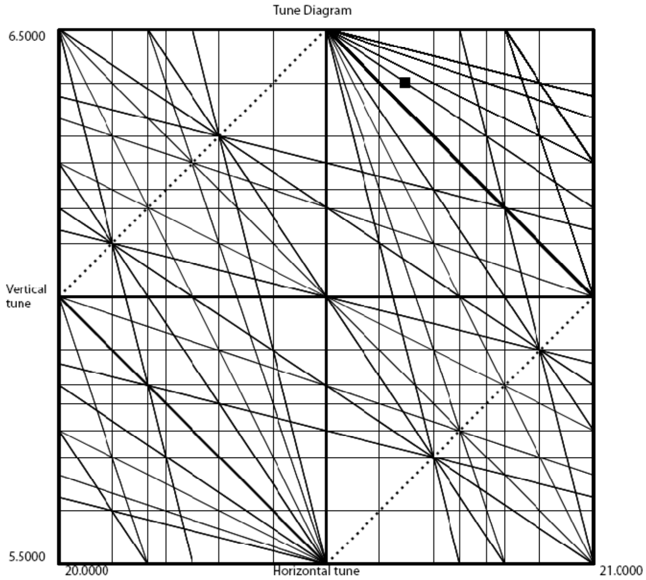


Fig. 2: The layout of the Betatron tunes

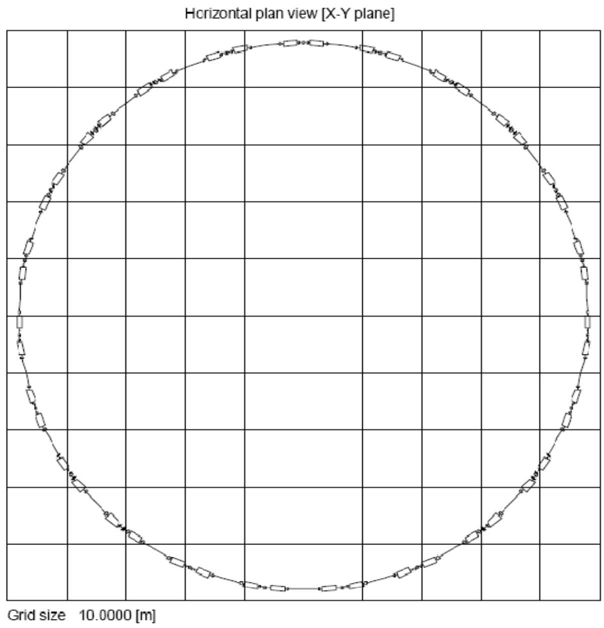


Fig. 3:The layout of the Circumference that has 23 straight sections which have total distance 110.4 [m].

## THE TBA LATTICE

For the TAC at 3.56 GeV, the TBA has been studied with the equal length dipoles which are the magnetic field of the middle dipoles by a factor of √3 larger than that of outer dipoles.

$$\frac{L_2^3}{\rho_2^2} = 3\,\frac{L_1^3}{\rho_1^2} \qquad (5)$$

†; Figure 2

The matching condition of Eq. (5), based on the small angle approximation, requires $L_2=3^{1/3}L_1$ for isomagnetic storage rings, or $\rho_1=\sqrt{3}\rho_2$ for storage rings with equal length dipoles.

Table 3- Main parameters for quads and dipol magnets

| | Quadrupoles | Dipol 1 | Dipol 2 |
|---|---|---|---|
| Number | QF1/QD1/QD2 | M1 | M2 |
| Length [mm] | 200/200/150 | 1600 | 1600 |
| Strength[1/m$^2$] | 2.8/-1.8/-1.5 | 0.36 | -0.245 |
| Curvature[1/m] | ------ | 0.0619 | 0.1072 |
| Angle [rad] | ------ | 0.099039 | 0.171519 |

Table 4- Main parameters of the storage ring.

| | |
|---|---|
| Achromatic structure | TBA |
| Nominal energy [GeV] | 3.56 |
| Superperiod | 17 |
| Circumference [m] | 197.54 |
| Main radius [m] | 31.44 |
| Harmonic number | 331 |
| Max. Beam Current [mA] | 400 |
| R. F. Frequency [MHz] | 502.34 |
| Energy loss/turn [MeV] | 1.180 |
| Total radiation power [kW] | 471.812 |
| Energy spread [%] | 0.07716 |
| Momentum compaction factor | 0.003006 |
| Beam lifetime [h] | 20.2 |
| Horizontal emittance-$\varepsilon_x$ [μm.rad] | 0.48 |
| Vertical emittance-$\varepsilon_y$ [nm.rad] | 4.833 |
| Coupling [%] | 1 |
| Energy acceptance [%] | 4.239 |
| Betatron tunes♣ [$Q_x$/$Q_y$] | 9.42/3.46 |
| Natural chromaticities [$\xi_x$/$\xi_y$] | -20.03/-27.72 |
| Beta functions | |
| Horizontal (max/min)-[m] | 15.523/0.377 |
| Vertical (max/min)-[m] | 57.329/4.724 |
| Maximum dispersion [m] | 0.029 |
| Straight section [m/%] | 4/34.4 |

Around 34.4% of the circumference is devoted to straight sections(Fig. 6). Figure 4 shows the beta functions in the unit cell of the storage ring.

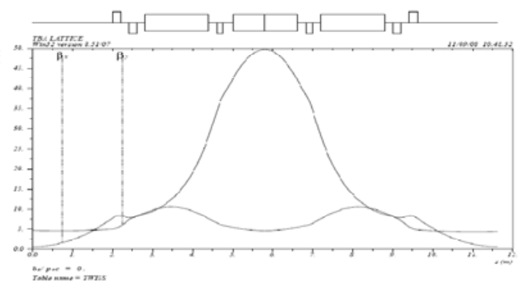

Fig. 4: Beta functions for 17 period TBA lattices.

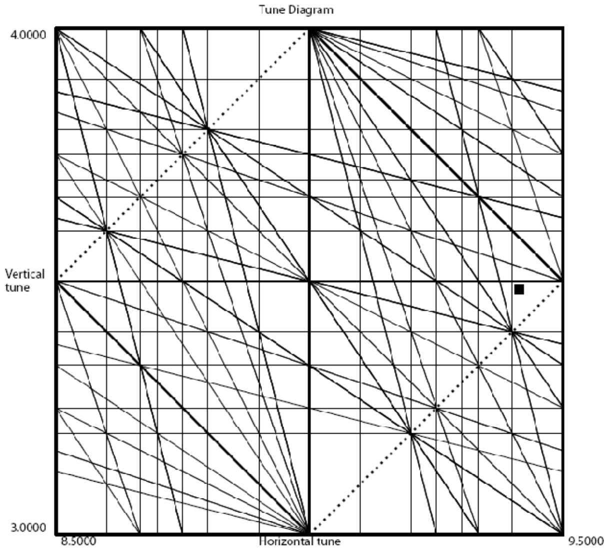


Fig. 5: The layout of the Betatron tunes.

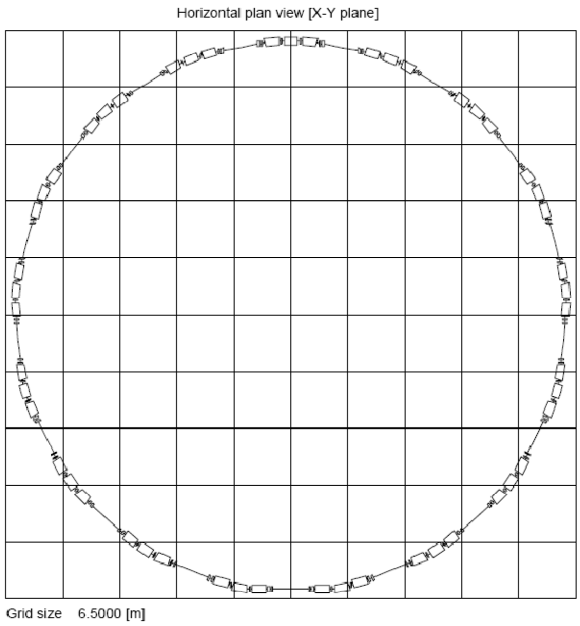


Fig. 6:The layout of the Circumference that has 17 straight sections which have total distance 136 [m].

## CONCLUSIONS

For the TAC at 3.56 GeV, in spite of two kinds of achromat which compared DBA and TBA lattices to meet the design goal, have been studied, still, they need to Dynamic Aperture(DA) Optimization and alignment tolerances.

The optical results of the first study that is a DBA lattice that is a type of lattice composed of cf-bending magnets and quadrupole doublet, look better than the second study that is a TBA lattice.

♣; Figure 5

For the better results about TBA, the other option that is the length of the dipoles is $\phi$ a factor of $3^{1/3}$ longer than that of outer dipoles, should be chosen.

## REFERENCES

[1] D. Einfeld, J. Schaper, M. Plesko, "A Lattice Design to Reach the Theoretical Minimum Emittance for a Storage Ring", EPAC96, WEP038G.

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