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TOWARDS A DIFFRACTION LIMITED STORAGE RING*

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Abstract

A robust lattice design for a 500 m circ. tunnel, as another step towards a "Diffraction Limited" Storage Ring, based on first principles and best practices, is presented (e.g. $\varepsilon_x \sim \lambda / 4\pi = 8$ pm · rad @ 1 Å = 12.4 keV; and a beam energy of ~3 GeV). In other words, exploratory, strategic work. As the aviation concept: "To stay ahead of the power curve".

INTRODUCTION

MAX IV has been the first practical and robust implementation of a 7-Bend-Achromat [1,2], i.e., "Predictable Results" [3]; which begun operation 2016. In particular, it has introduced a paradigm shift in the design philosophy for the "Engineering-Science" in the quest for a Diffraction Limited Storage Ring (DLSR) [4]. Besides, it's construction (by necessity) has been innovative and cost effective (e.g. outsourcing by built-to-Print, concrete girders, etc.).

Similarly, SLS-2 [5,6] has introduced a systematic method for controlling the linear optics beyond some 20 years of TME inspired paper designs; by introducing reverse bends [7,8] to disentangle dispersion and focusing, which enables longitudinal gradient bends to efficiently reduce the emittance.

While the conceptual design for the former initially has been met by a naysayer or two, operating facilities now either is [9], or have plans to, upgrade; by a "Rip-&-Replace" [5,10-13]. In industry the phenomenon is known as: "Disruptive Technology".

A key insight for the design of and R&D for MAX IV has been miniaturization; enabled by leveraging the Engineering-Science know-how provided by: MAX-I -> MAX-II -> MAX-III.

Similarly, since permanent magnets are well understood for insertion devices, i.e., predictable results, they now provide another opportunity (or risk); to "Push the envelope" further, see Fig. 1.

PRELIMINARY CONSIDERATIONS

Preliminary Concept: 19-BA

The basic requirements are summarized in Table 1. By numerical simulations and optimizations of the number of unit cells and cell tune, a 19-BA with $\bar{\nu}_{\text{cell}} = [4/16, 1/16]$ and a natural emittance of $\varepsilon_x = 16$ pm·rad (ignoring the impact of IBS) was obtained as a baseline lattice for a preliminary concept [14], see Table 2 and Figs. 2 and 3.

*Exploratory strategic work conducted at MAX IV winter 2016-2017.
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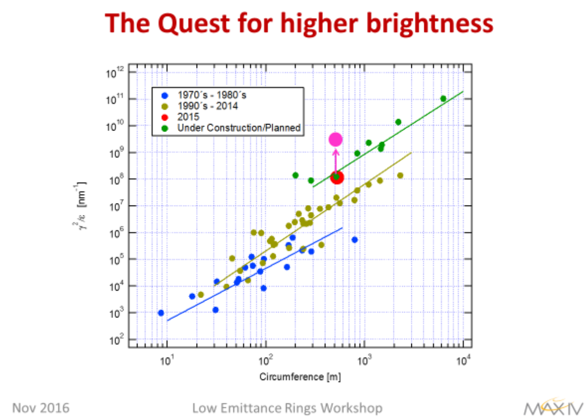

Figure 1: The Quest for Higher Brightness [14].

Table 1: Requirements

Energy	~3
Hor/Ver Emittance [pm·rad]: Round Beam	~10
On-Momentum Dynamic Aperture [mm]	~2 mm
Off-Momentum Dynamic Aperture	~3%
Touschek Life Time [hrs]	~5hrs
Momentum Spread	$< 1 \times 10^{-3}$
Magnet Reference Radius R_{ref} [mm]	5

Table 2: Global Parameters for 19-BA

Circumference [m]	527.7
Energy [GeV]	3
Horizontal Emittance [pm·rad]	16
Normalized phase advance $\bar{\nu}$	[101.2, 27.32]
Linar Chromaticity	[−100.2, −126.0]
Linear momentum Compaction	5.3×10^{-5}
Momentum Spread [%]	0.092

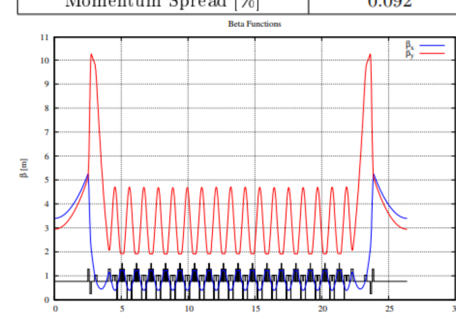

Figure 2: Linear optics for 19-BA.

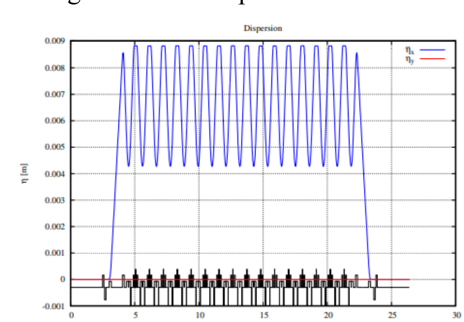

Figure 3: Horizontal linear dispersion for 19-BA.

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A 3rd Order Achromat: 18-BA

However, the resonance $4\nu_x = 1$ is systematically driven for the 19-BA structure. A 3rd order achromat [15,16] can be obtained by changing to $\bar{\nu}_{\text{cell}} = [5/15, 1/15]$. However, the increase of the horizontal cell tune leads to an excessive increase of the horizontal linear chromaticity. So, instead, one may consider $\bar{\nu}_{\text{cell}} = [4/15, 1/15]$; by reducing the number of cells to a 18-BA, see Table 3 and Figs. 4 and 5.

Table 3: Global Parameters for 18-BA

Circumference [m]	560
Energy [GeV]	3
Horizontal Emittance [pm·rad]	18
Normalized phase advance $\bar{\nu}$	[102.2, 68.18]
Linar Chromaticity	[−124.8, −118.2]
Linear momentum Compaction	4.4×10^{-5}
Momentum Spread [%]	0.094

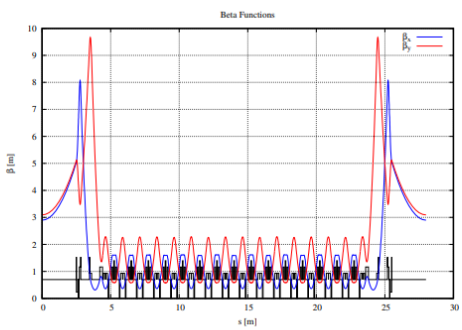

Figure 4: Linear optics for 18-BA.

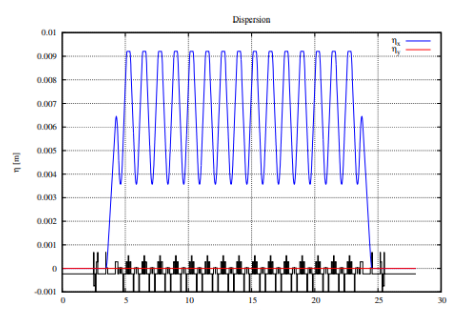

Figure 5: Horizontal linear dispersion for 18-BA.

BEAM DYNAMICS BENCHMARK

Our beam dynamics benchmark comprises of:

- Tune footprint, see Fig. 6.
- On and off-momentum Dynamic Aperture (DA) for Bare Lattice, see Fig. 7.
- On and off-momentum DA for the real lattice (i.e., with mechanical mis-alignments, magnetic field errors, control of closed orbit, and beta-beat), see Figs. 8 and 9.
- On and off-momentum frequency maps for real lattice, see Figs. 10 through 13.
- "Touschek Tracking", see Fig. 14.
- Longitudinal phase space, see Fig. 15.

from which it is clear that the design is robust [17].

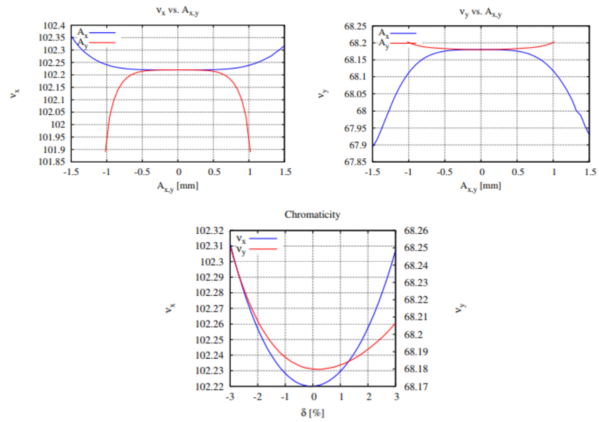

Figure 6: Tune footprint for 18-BA.

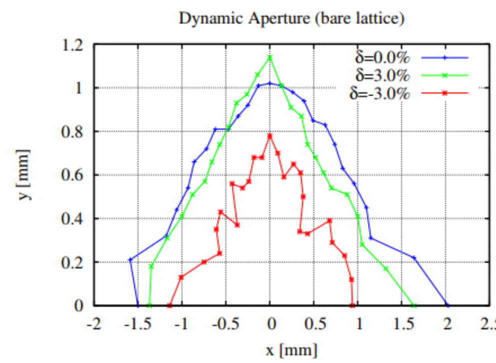

Figure 7: Dynamic aperture for 18-BA; bare lattice.

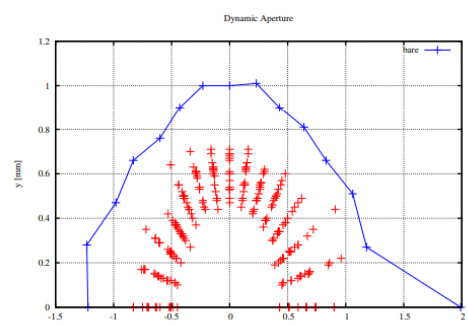

Figure 8: Dynamic aperture for 18-BA; real lattice.

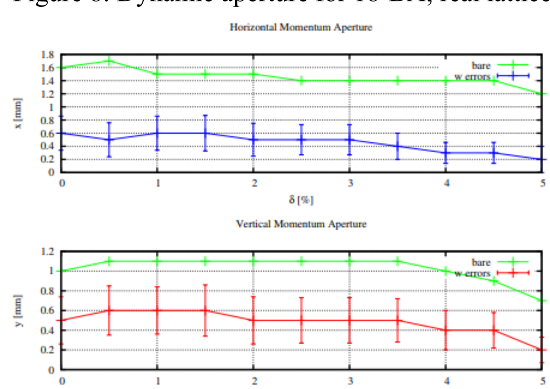

Figure 9: Off-momentum dynamic aperture for 18-BA; real lattice.

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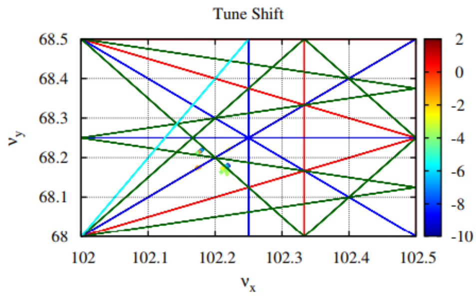

Figure 10: Tune footprint for 18-BA; real lattice.

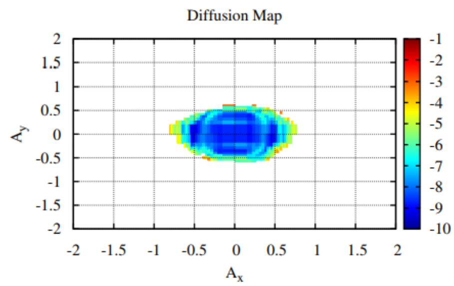

Figure 11: Diffusion map for 18-BA; real lattice.

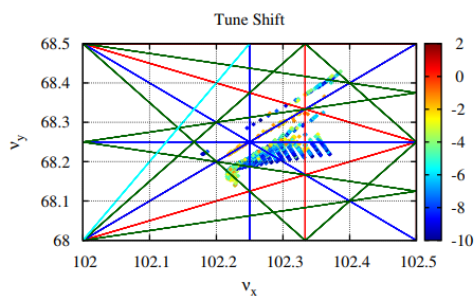

Figure 12: Off-momentum tune footprint for 18-BA; real lattice.

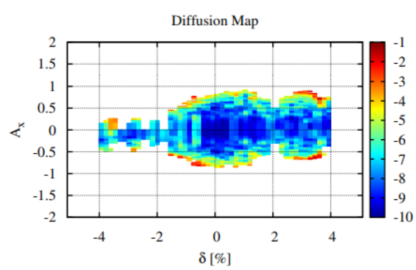

Figure 13: Off-momentum diffusion map for 18-BA; real lattice.

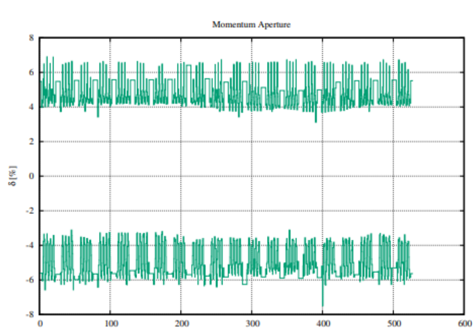

Figure 14: "Touschek tracking" for 18-BA; real lattice.

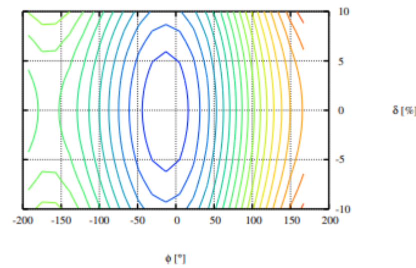

Figure 15: Longitudinal dynamics for 18-BA.

SYSTEMATIC CONTROL OF H$_2$

Control of the quadratic Hamiltonian, H_2, i.e., the linear optics, can be refined by introducing longitudinal gradient dipoles and reverse bends [7,8]. The result is summarized in Table 4 and Fig. 16.

Table 4: Global Parameters for 8-BA with Longitudinal Gradient Dipoles and Reverse Bends

Circumference [m]	533.6
Energy [GeV]	3
Horizontal Emittance [pm·rad]	23
Normalized phase advance $\bar{\nu}$	[73.94, 27.82]
Linar Chromaticity	[−179.0, −65.98.2]
Linear momentum Compaction	-3.9×10^{-5}
Momentum Spread [%]	0.089

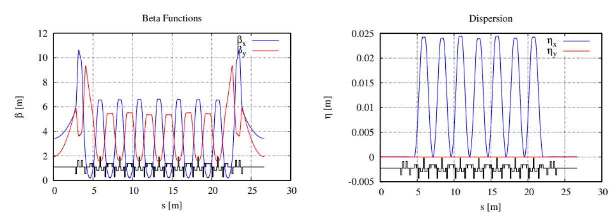

Figure 16: Linear optics and horizontal linear dispersion for 18-BA.

CONCLUSIONS

A robust lattice design, based on first principles and best practices, for a 500 m circ. tunnel with a natural emittance of ε_x~20 pm·rad for a beam energy of 3 GeV (ignoring the impact of IBS) has been presented; as another step towards a "Diffraction Limited" Storage Ring (DLSR).

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