ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA144

SCALING OF HYBRID MULTI BEND LATTICE CELLS

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Abstract

The hybrid multi bend (HMBA) lattice has been introduced to the accelerator community with the ESRF-EBS storage ring. Scaling an HMBA storage ring (SR) to different number of cells or cell length may lead to loss of performances, in terms of dynamic aperture (DA), momentum acceptance (MA) and natural horizontal emittance of the resulting SR. In this article we present several (non-exhaustive) scaling rules that guarantee minimal performance loss. A comparison of lattice cells with varying number of dipoles shows that the H6BA cell outperforms other layouts in both, DA and MA, while a larger number of dipoles per cell is required to produce the lowest emittance.

INTRODUCTION

To adapt a given SR optics to an existing light source layout, or to seek for improved beam and lattice parameters (e.g. lower emittance) it is often needed to scale a lattice cell to different number of cells and different lengths. This process often leads to loss of final DA and MA performances. We present here a list of actions that we consider necessary in order to scale a lattice cell and keep the largest possible DA and MA.

The scaling is aimed to change the number of cells that compose a lattice or the total cell length. For this task, the use of dedicated matching scripts tailored to the specific cell are mandatory to achieve all the wished optics parameters. The software used for all 6D tracking simulations is accelerator toolbox [1, 2]. DA and MA computations for 2048 turns are performed exploiting the ESRF computing cluster.

In the following, four different lattice cells optics are compared: DBA [3], H6BA [4], H7BA [5] and H9BA [6] shown in Fig. 1. A table of parameters for these four lattice cells is shown in Table 1.

EXPECTED SCALING LAWS

The horizontal natural emittance ϵ_h scaling law as a function of the number of dipoles in the lattice cell [7] states that

$$\epsilon_h \propto \frac{E^2}{N_{\text{bend}}^3},$$

where E is the energy of the e^- beam, and N_{bend} is an integer number of dipoles per cell.

According to Ref. [4], DA scales inversely with the product of the two sextupole families strength, K_{SF} and K_{SD}, for

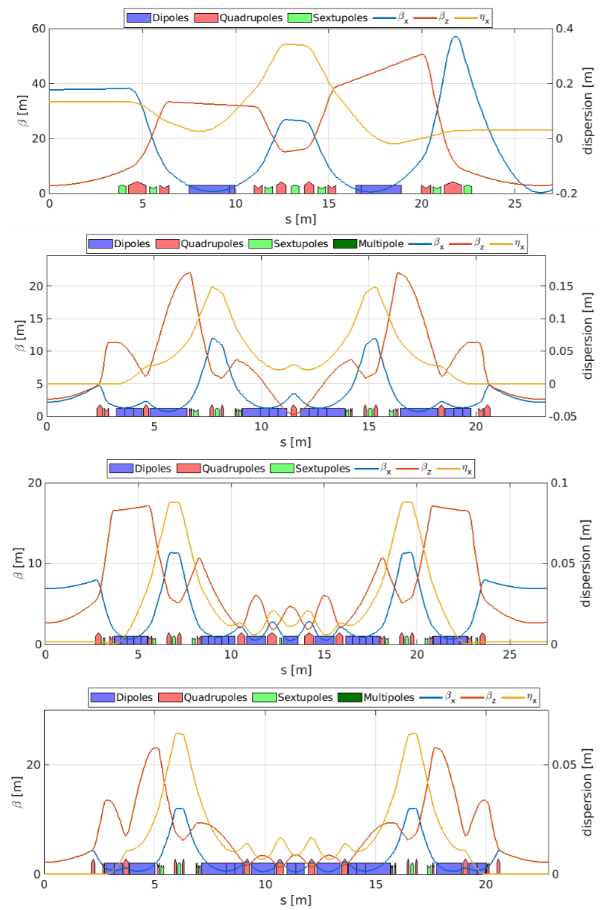

Figure 1: (Top to bottom) DBA, H6BA, H7BA and H9BA cells optics and magnet layout.

Table 1: Parameters of SRs Scaled to 6 GeV and 32 Cells

Year	DBA 1994	H7BA 2019	H6BA -	H9BA -
Circ. (m)	844	844	736	730
ϵ_h (pm rad)	3985	133	437	75
Q_h	36.44	76.21	56.2	88.2
Q_v	13.39	27.34	28.2	26.2
δ_E (%)	0.106	0.094	0.11	0.11
σ_z (mm)	3.43	2.9	3.4	2.4
J_x	1.00	1.51	1.78	1.98
U_0 (MeV)	4.75	2.61	2.59	2.28

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chromaticity correction,

$$DA \propto \frac{1}{K_{SF}K_{SD}}.$$

With respect to MA, varying the SR total length (with fixed cell length) appears to have almost negligible effect on MA for a fixed cell length. This behaviour might be expected since lower dispersion cancels out the effect of stronger sextupoles. In fact, dipoles fields decrease linearly with the inverse of the number of cells, therefore dispersion decreases linearly, and the sextupoles strength for chromaticity correction [8] increase linearly.

SCALING THE NUMBER OF CELLS

The basic lattice cell scaling to different number of cells involves only dipoles. The bending angle is corrected proportionally to the inverse of the number of cells in the lattice, and entrance and exit face angles are scaled accordingly.

The lattice total phase advance will be proportional to the number of cells as well. In order to fairly compare performances, a change of the fractional part of the tune must be envisaged. Instead of the basic approach using two quadrupole families, a matching script targeting the main lattice parameters has been used for every cell to keep them unchanged as much as possible. This leads to a unique determination of all the quadrupole gradients in each lattice cell.

Similar conditions are used for the matching of all four cells studied in this paper, for example, for the H7BA EBS lattice the optics parameters targeted in the matching to define the gradients of the nine quadrupoles are:

- total cell phase advance (with fractional part fixed for comparison in all lattices to (.21, .34))
- β_h and η_h at the center of the straight section
- β_h, α_v at the center of the first focusing sextupole
- the phase advance among focusing sextupoles in both planes
- β_v at the center of the cell.

In addition, chromaticity is set in all simulations and for all lattices to $(6, 4)$ with two sextupole families. As described above, the sextupole strengths required to correct the natural chromaticity in each cell increase linearly with the number of cells due to the reduced dispersion. It is possible to visualize simultaneously in Fig. 2 the emittance scaling, the area of the DA normalized by the beta at the injection location (the size of the circles and the same value reported as number) and the average local MA over one cell (the color of the circles) for each lattice.

Effect of Multipole Scaling

In Fig. 2 sextupoles, octupoles and decapoles are scaled according to the dispersion at their location. For sextupoles,

$$K^N_{\text{sext}} \propto \left(\frac{\eta_{h,0}}{\eta_{h,N}}\right) K^0_{\text{sext}},$$

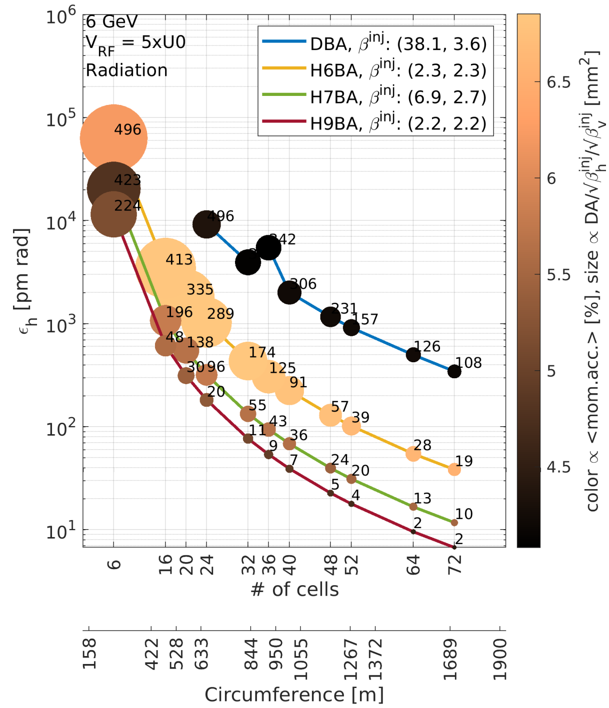

Figure 2: Horizontal natural emittance, DA (size of circle and numbers on figure) and average MA (color) as a function of lattice cell and total number of cells.

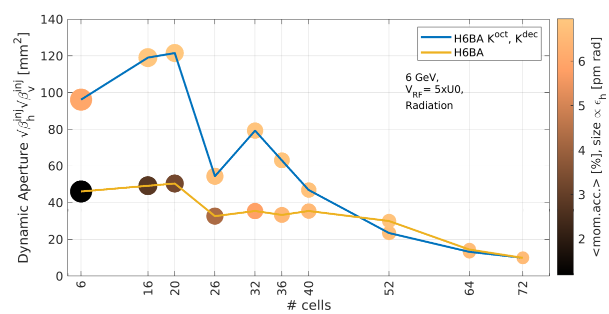

Figure 3: Effect of octupole and decapole scaling with dispersion on normalized DA and MA (color), as a function of lattice cell and total number of cells. The dots size is proportional to the natural horizontal emittance.

as required for chromaticity correction. For octupoles and decapoles, the applied corrections are

$$K^N_{\text{oct}} \propto \left(\frac{\eta_{h,0}}{\eta_{h,N}}\right)^2 K^0_{\text{oct}},$$

$$K^N_{\text{dec}} \propto \left(\frac{\eta_{h,0}}{\eta_{h,N}}\right)^3 K^0_{\text{dec}},$$

where η_h is the dispersion at the magnet, K_{oct} the octupole gradient, and K_{dec} the decapole gradient, and the indexes 0 and N indicate the initial and final value for N cells. As an example, in Fig. 3, the DA and MA of the H6BA lattice cell improves considerably when using this scaling laws compared to taking no action.

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DA and MA Scaling with Number of Cells

In order to verify the relations mentioned previously, Fig. 2 may be observed from a different point of view in Figs. 4 and 5. The agreement with the expected relations for DA is rather clear, in particular for the H7BA and H9BA cells. For MA the dependence may be approximated with a constant line as expected for all cases, except the H9BA.

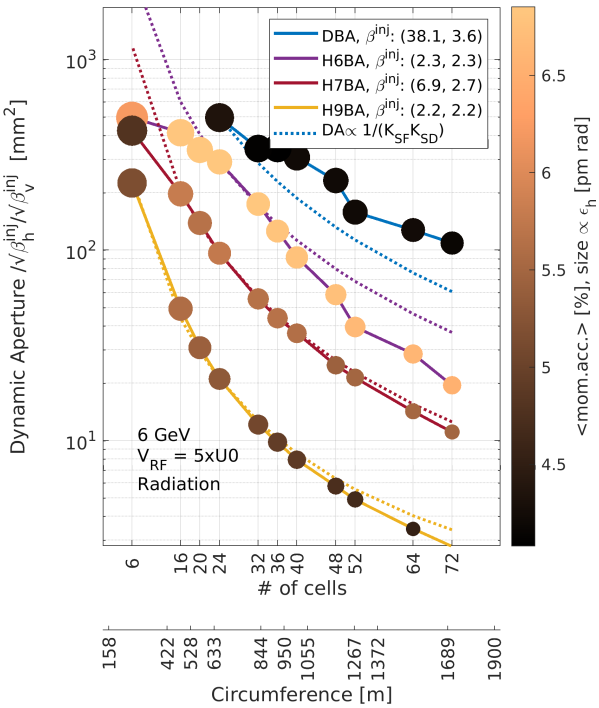

Figure 4: Normalized DA and MA (color), as a function of cell type and total number of cells. The dots size is proportional to the natural horizontal emittance.

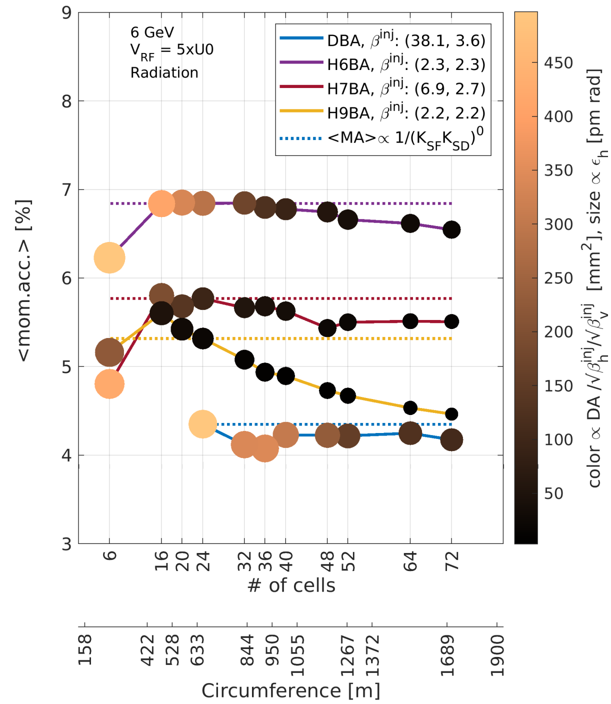

Figure 5: MA and normalized DA (color), as a function of lattice cell and total number of cells. The dots size is proportional to the natural horizontal emittance.

SCALING THE CELL LENGTH

To scale the lattice cells to different lengths all magnets and drift spaces are scaled proportionally. The quadrupole gradients are

$$K_{\text{quad}}^{L_1} = K_{\text{quad}}^{L_0} \left(\frac{L_0}{L_1}\right)^2 ,$$

where L_0 and L_1, are the initial and final cell length respectively; the first L_0/L_1 factor accounts for integrated strengths and the second for the changed distance among magnets. Stable optics similar to the initial ones are obtained thanks to this scaling. As for the scaling of the number of cells, multipoles gradient scaling with dispersion are applied as well as a final cell optics matching. Chromaticity is fixed to (6, 4) in all cases. Figure 6 displays the performances of 32 cells lattices when changing the total individual cell length.

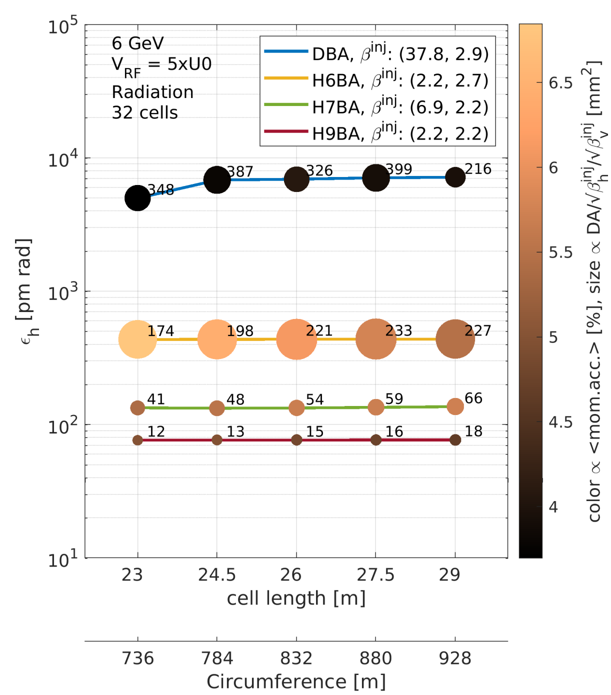

Figure 6: Horizontal natural emittance, DA (size of circle) and average MA (color), as a function of lattice cell and cell length with fixed number of cells (32).

CONCLUSIONS

Several lattices cells have been scaled varying the number of cells and cell length following a full cell matching and scaling of quadrupolar and multipolar gradients. The performances in terms of DA and MA are consistent with the expected scaling laws. The H6BA lattice appears to be the most flexible design and gives for all the studied cases better performances compared to H7BA and H9BA at the price of a larger horizontal natural equilibrium emittance.

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