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Quantum Excitation Estimates for CEBAF Energy Upgrades

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Abstract

We present estimates for quantum excitation driven growth of emittance and momentum spread in energy-upgraded CEBAF recirculators. Two scenarios are given: that of a direct energy upgrade of CEBAF, and that of a significantly modified machine, the <u>S</u>uperconducting <u>U</u>pgrade of the <u>P</u>resent <u>E</u>lectron <u>R</u>ecirculator <u>CEBAF</u> (SUPERCEBAF), one concept for which has been described in some detail elsewhere [1].

Model

The estimates are based on storage ring excitation formulae due to Sands [2]. These were summarized in early CEBAF lattice documentation [3], and later modified to reflect a more rigorous treatment by Sands of excitation effects in a transport system [4]. They give the rms momentum spread and emittance growth generated by quantum excitation during 180^{o} of bending through a radius r at energy $g m_0 c^2$. The relations are as follows.

$$s_E^2 = 1.18\times10^{-33}\ \mathrm{GeV}^2\ \mathrm{m}^2\,\frac{g^7}{r^2}$$

$$\Delta e = 7.19 p \times 10^{-28}\ \mathrm{m}^2\ \mathrm{rad}\,\frac{g^5}{r^2}\langle H\rangle$$

In these relations,

$$\langle H\rangle = \left(\frac{1}{L}\right)\int_{\mathrm{bends}} \frac{\mathrm{ds}}{b}\left[h^2 + \left(bh' - \frac{1}{2}b'h\right)^2\right]$$

is the average (in the dipoles) of the quantum excitation function H; L is the orbit length, and r the orbit radius, in the bends. In these estimates, an $\langle H\rangle$ value of 0.2 m was taken for all cases. This is consistent with values typical to both the actual CEBAF transport system [5] and concepts for SUPERCEBAF [6].

Certain features of the estimates are worthy of note.

- They do not include contributions of spreader/recombiners; these were deemed small, as the spreader/recombiner bend radii increase and the bend angles decrease as the beam progresses through the machine.

- The above expressions are derived from results based on a storage ring model. The estimate for the momentum spread is applicable to a beam line, but that for the emittance degradation has been modified from a relation stated earlier [7] to follow a more rigorous treatment by Sands [8]. The detailed Sands result differs from the above primarily in that the expression for Δε contains integrals of the unaveraged excitation function *H* modulated by sinusoids of the betatron phase. The above result assumes the convolution of *H* with the sinusoids simply phase averages to <*H*> times the average of the sinusoids, which was taken to be ½. This is reasonable for a periodic lattice several betatron wavelengths long, but a careful evaluation of the emittance dilution may differ by a factor of two or so from the result of the above formula. The stated expression for Δε will, however, give a reasonable order of magnitude estimate.
- Two scenarios are considered – a direct CEBAF upgrade and a more radical machine rebuild. For each scenario there is an estimate of momentum spread and emittance as a function of beam final energy, and based on this, an estimate of the $6s$ ($s = \sqrt{be + (h s_E/E)^2}$) spot size as a function of energy at a location with ~2m of dispersion and a beam envelope of ~50 m. This represents an upper operational limit on the phase space volume, inasmuch as when the 6σ spot size reaches ~ 1 cm, significant scraping may occur and machine operation could be difficult.

Results

Scenario 1: Direct CEBAF Energy Upgrade

The estimates were in this case based on bend radii employed in the existing CEBAF lattice and an approximate value <*H*> = 0.2 m for all arcs. Figure 1 presents the results for momentum spread and emittance; Figure 2 gives the spot size estimate. Injection energy scaling is assumed. Based on the 1 cm spot size criterion discussed above, this upgrade path may be limited to energies of less than 18 – 20 GeV by quantum excitation. Magnet field, powering, and cooling limitations may constrain upgrades to lower energies.

Scenario 2: Upgrade to SUPERCEBAF Configuration

The estimates were in this case based on bend radii and <*H*> values defined by the follo

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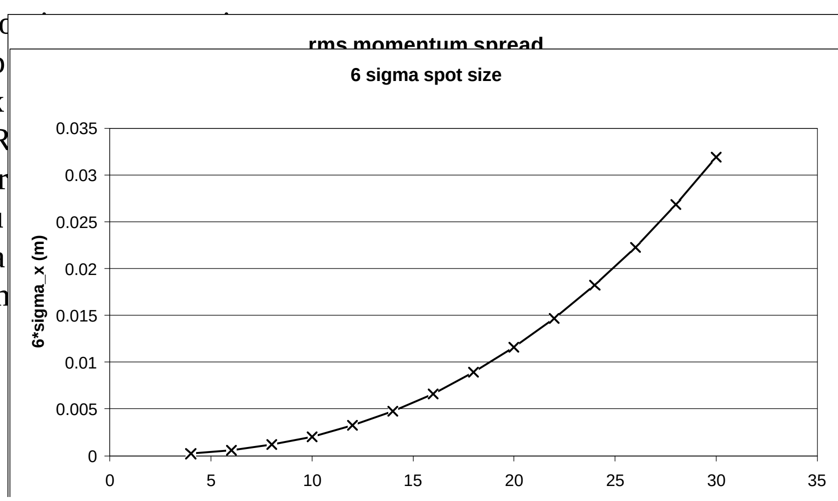

Figure 2: 6*s* spot size for direct CEBAF upgrade. A 1 cm aperture limit is exceeded at ~18 – 20 GeV.

The radii and <*H*> values for the six lowest energy arcs are the same as in the corresponding six highest energy arcs of Scenario 1. The radii and <*H*> values for the three highest arcs are taken from a design exercise detailing a 16 GeV machine in the CEBAF tunnel [9]; they are *r* =53 m and <*H*> = 0.167 m. Figure 3 presents the results for momentum spread and emittance; Figure 4 gives the spot size estimate. Injection energy scaling is assumed. Based on the 1 cm spot size criterion discussed above, this upgrade path may be limited to energies of less than 24 GeV. Seeking high-energy arc solutions with higher dipole packing fraction, larger bend radii, and lower <H> may raise this limit. We note this requirement is somewhat of an oxymoron; higher packing fraction and larger bend radii will in general tend to drive a lattice toward higher <*H*>.

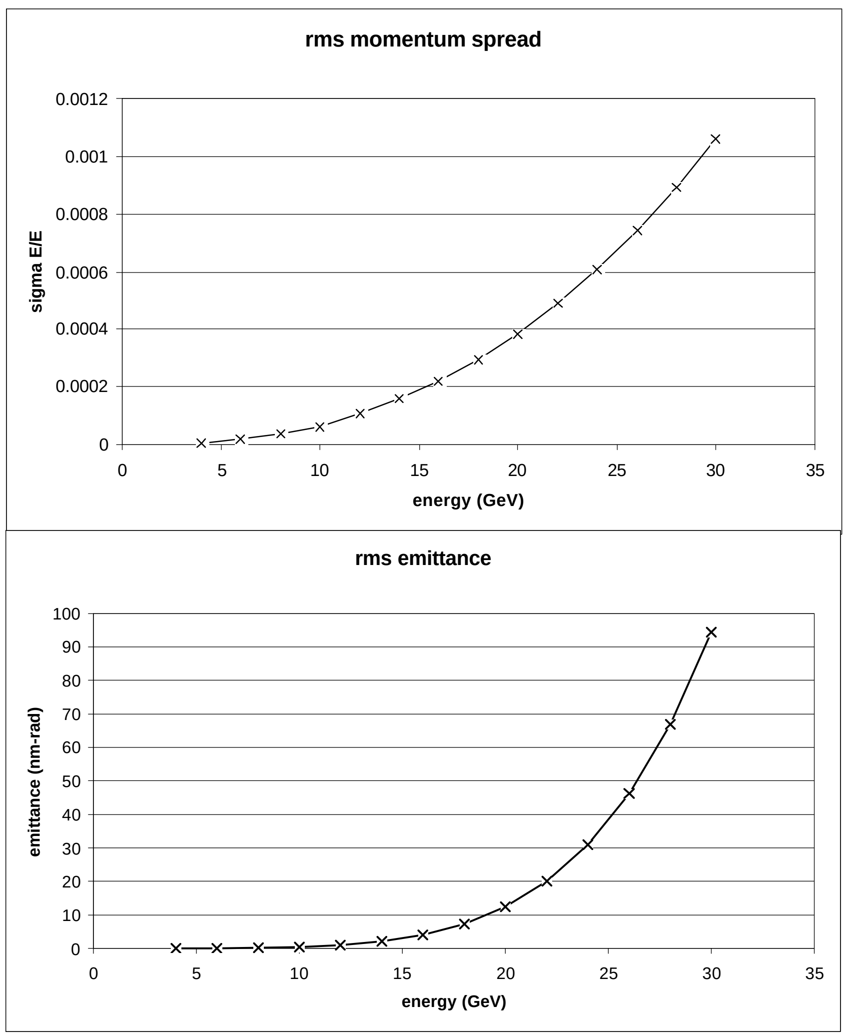

Figure 3: Momentum spread and emittance for SUPERCEBAF.

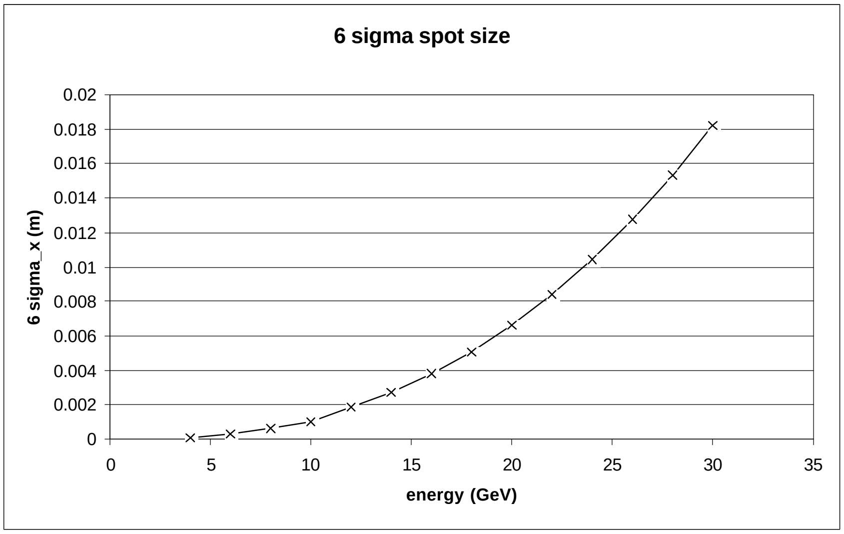

Figure 4: 6*s* spot size for SUPERCEBAF. A 1 cm aperture limit is exceeded at ~24 GeV.

Acknowledgements

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References

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