Quad Tolerances

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December 20, 2011

Summary

The ripple on the quad power supplies can be specified at 0.1% for all quad power supplies. The pole positioning can be $50\,\mu$m ($100\,\mu$m in dia.) for all.

Basic considerations

The focal length of a quadrupole is f:

$$\frac{1}{f} = \frac{\int G dz}{B\rho} = \frac{K}{B\rho},$$

where K is the integrated quad strength.

An error results in a mismatch compared with the desired ellipse if the error $\delta(x/f)$ becomes comparable with the local angular spread ϵ/x. Thus we have the condition:

$$\delta(1/f) \ll \frac{\epsilon}{x^2}$$

or,

$$\delta(1/f) \ll \frac{1}{\beta_{x,y}}$$

As $\frac{d(1/f)}{1/f} = \frac{dI}{I}$, we have the following condition in the allowed variation of the quad current I:

$$\frac{dI}{I} \ll \frac{f}{\beta_{x,y}} \equiv \hat{I}. \tag{1}$$

Similarly, we can find a condition for the aperture and hence the tolerance on the positioning of the poles:

$$V = V_0 \frac{x^2 - y^2}{2a^2}$$

and

$$B_x = \partial_x V = \frac{x}{a^2} V_0$$

and gradient G is

$$G_x = \partial_x B = \frac{V_0}{a^2}$$

Thus

$$\frac{d(1/f)}{1/f} = 2\frac{da}{a}$$

The condition is:

$$da \ll \frac{af}{2\beta_{x,y}} \equiv \hat{a} \tag{2}$$

We have tabulated $\hat{I}$ and $\hat{a}$ for all the quadrupoles, in the following table; all quads have $a = 26$ mm. For those whose tune changes depending upon mode of operation (photofission, ERL, RLA), only the worst (smallest) value is given.

How much smaller?

The symbol $\ll$ hides some fuzziness and so requires further thought. The question is: How large a factor is required? For current ripple, we must be quite stringent, as it results in a real emittance growth unless there is a linear correction being imposed with bandwidth similar to the ripple (likely 60 Hz). This is unlikely. Thus, I impose a factor 40.

For pole positioning, the error is only systematic, and can be corrected by varying the strength slightly. The only inconvenience is that quads that are in a symmetric arrangement and constrained to match, will not match well. Thus, we use a looser factor of 10 here.

Results

Name	$\hat{I}$	$\hat{a}/\mathrm{mm}$
EMBT:Q1	0.2	3.2
EMBT:Q2	0.10	1.3
EMBT:Q3	0.6	7.3
EMBT:Q4	0.8	10.0
EMBT:Q5	1.0	13.0
EMBT:Q6	0.6	7.5
EMBT:Q7	0.4	4.6
EABT:Q1	0.12	1.6
EABT:Q2	0.13	1.7
EABT:Q3	0.2	2.2
EABT:Q4	0.2	2.8
EABT:Q5	0.2	2.4
EHAT:Q1	0.2	2.5
EHAT:Q2	0.13	1.7

Name	$\hat{I}$	$\hat{a}/\mathrm{mm}$
EHDT		
EHDT:Q3	0.7	9.3
EHDT:Q4	0.6	8.4
EHDT:Q5	0.3	4.1
EHDT:Q6	1.1	15.1
EHDT:Q7	0.3	4.1
EHDT:Q8	1.1	14.6
$2 \times 26^\circ$ Dogleg		
EHBT:Q1	0.054	0.70
EHBT:Q2	0.051	0.67
EHBT:Q3	0.051	0.66
EHBT:Q4	0.13	1.6
EHBT:Q5	0.59	7.6
EHBT:Q6	0.13	1.7
EHBT:Q7	0.051	0.66
EHBT:Q8	0.067	0.87
EHBT:Q9	0.060	0.78

Name	$\hat{I}$	$\hat{a}/\text{mm}$
Matching		
EHBT:Q10	0.09	1.2
EHBT:Q11	0.66	8.5
EHBT:Q12	1.5	19.
EHBT:Q13	0.25	3.3
N-S Periodic		
EHBT:Q14–Q25	0.189	2.5
$2 \times 24^\circ$ Vert. Dogleg		
EHBT:Q26,Q33	0.19	2.4
EHBT:Q27,Q32	0.058	0.7
EHBT:Q28,Q31	0.10	1.3
EHBT:Q29,Q30	0.042	0.5
$2 \times 34^\circ$ Bend		
EHBT:Q34,Q41	0.3	3.6
EHBT:Q35,Q40	0.3	4.4
EHBT:Q36,Q39	0.04	0.6
EHBT:Q37,Q38	0.06	0.8

Name	$\hat{I}$	$\hat{a}/\mathrm{mm}$
Single FODO Cell		
EHBT:Q42,Q43	0.26	3.4
$2 \times 22^\circ$ Dogleg		
EHBT:Q44,Q49	0.3	3.4
EHBT:Q45,Q48	0.04	0.5
EHBT:Q46,Q47	0.08	1.1
Matching to Target		
EHBT:Q50,Q54	0.24	3.1
EHBT:Q51,Q55	0.33	4.3
EHBT:Q52,Q56	0.05	0.6
EHBT:Q53,Q57	0.10	1.2

Thus we see that the smallest $\hat{I}$ is 4%, so, applying the factor of 40, 0.1% power supply ripple is sufficient for all.

The smallest $\hat{a}$ is 0.5 mm, so a pole positioning error of $50\,\mu$m is sufficient.