LS–4
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R. Martin

High Brightness Lattices

I had not realized until I heard Keith Symon describe the situation at Aladdin on Thursday, November 1 just how low a current limit it had. I now submit to you that there is no way an electron machine designed for 1A could be limited to 1–2 mA, especially after such a long tuneup time, by misalignments, poor diagnostics, low injection energy, nor the low injector current. The aperture couldn't be wrong by more than a factor of 2–4 since the low current lifetime due to gas scattering is the calculated value. Other machines with low injection energy get hundreds of mA. A microtron current with 1 mA output should still allow accumulation of 50–100 mA in the ring. Low injection current then isn't the problem. I found the rapid change of lifetime with current at this level very surprising. How does one account for the drastic change in lifetime between 1 mA and 4 mA? It's much too low a current for this to happen for any reason except a very fundamental problem with stop-bands.

A superficial examination of the Aladdin lattice indicates that the twenty–four quads in the 4 long straight sections in triplet sets give $\sim 90°$ phase advance per triplet and so account for $\sim$ 2 units of tune. The remaining 5 units must come from the 12 sets of doublets or a phase advance of $\sim 150°$ per quad pair (in the associated drift spaces). The phase advance, for a matched beam, is extremely sensitive to momentum at this point. The situation must be much worse for an unmatched beam, or for one that goes out of the matched condition because of magnet ripple, space change forces due to very small beam sizes, longitudinal effects or instabilities of any kind. If one calculates the phase advance of a matched beam through a perfect set of thin focusing lenses as a function of momentum the steepness of the curve and its proximity to the $\mu = 180°$ stop-band (of even a simple transmission line) at the momentum P_c becomes clear.

P/P_c	μ
1.0	180°
1.07	150°
1.1	145°
1.2	132°
1.5	109.5°
2.0	90°

To be only 7% away from a deadly stopband seems too close, particularly for a machine that has not yet been finely tuned, diagnostics not yet highly developed, and feedback and damping systems to control instabilities not operational. In addition the Aladdin beta function is non–symmetrical with respect to the quadrupoles. I would think this would make the machine even more sensitive.

It should be very easy to check whether or not this were the problem. One only needs to reduce the quadrupole currents to achieve a more normal and symmetrical $\mu = 90°$ lattice, ignoring for the moment the high brightness condition, and find out what happens to the beam lifetime and limiting current. It means reducing the tune to $\sim$ 5. The results might be dramatic.

If this lattice sensitivity were the problem with Aladdin what about the x–ray ring at Brookhaven? It likewise has the "high brightness" lattice. As near as I can tell, again superficially, the phase advance per focusing quadrupole set is about 145° in the horizontal plane. I count the singlet quadrupole between bending magnets as a complete focusing element in the horizontal plane. The phase advance per focusing set in the vertical plane is less than in the horizontal in the x–ray ring, whereas in Aladdin they are nearly identical. Could this account for being able to get 10–20 mA in the x–ray ring (in spite of low injection current) and only 1–2 in Aladdin? Notice also that the VUV ring at Brookhaven, which operates reasonably well at 200–400 mA with the same injector as the x–ray ring, has the standard 90° FODO lattice.

If these conjectures have any validity then what about other synchrotron light sources in the world, all of which seem to be operating in a reasonable way? Some of the parameters of dedicated synchrotron light sources are listed in the table. One can see that, aside from Aladdin and the NSLS x–ray ring, only the METRO tune of the BESSY machine has a high phase advance. One must conclude that "high brightness" lattices can be made to work. On the other hand the BESSY ring might have been much more stable and developed before the METRO tune was tried, especially since it had been made to work up to 350 mA as an x–ray ring with a "normal" tune. At low currents with the METRO tune the measured beam sizes are about a factor of 2.5 larger than predicted by theory. Since the beam size in electron machines is determined by the machine dynamics then the understanding of the effects of the METRO tune appear not to be complete.

My conclusion is that there is some cause for concern about the sensitivity of these "high brightness" lattices, and that it might be well to plan initially to bring such machines on with the more normal tunes we are all familiar with, much like they did at BESSY. These questions are obviously extremely important for the 6 GeV Light Source and experiments at both Wisconsin and Brookhaven might provide some useful information.

	Wisconsin	BNL (NSLS)		BESSY		Daresbury	KEK
	Aladdin	VUV	X–ray	X–ray	Metro	SRS	PF
E_{in} (MeV)	100	750	750	800	800	600	2500
Inj. Rate (mA/min)		3–6	3–6	120–150	30	25(Sb)	
Max I (mA)	4	400	20	320	130	300	250
e_h (theor)		9×10^{-8}	8×10^{-8}	2×10^{-6}	3×10^{-8}	1.5×10^{-6}	2.7×10^{-7}
e_v		9×10^{-10}	8×10^{-10}				2.7×10^{-7}
#Quads	48	24	56	32	32		58
#Pairs, Doublets or Triplets	20	12	16(24)	16	16		27
υ_h	7+	3.12	9.7	2.8	5.6	3.25	5.25
υ_v	7+	1.17	5.7	1.5	2.2	2.25	4.25
*Av. Ph. Adv/Q Doub. /or Q Trip.	126°	90°	218(146)	63°	126°	90°	70°

*Individual phase advances of sets of focusing elements and drift spaces might be higher because of different tunes for straight sections.