Synchrotron Radiation Power at CEBAF 12 GeV Upgrade

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Abstract

Synchrotron radiation (SR) power radiated by various dipole magnets at Arcs 6 through10 and also in the 12 GeV beam line is estimated for the 12 GeV Upgrade. Power redistribution effects due to transitions of the vacuum chamber are estimated. The SR power at the CEBAF 12 GeV Upgrade is compared to that at the VEPP-2M. The operational experience with VEPP-2M uncooled vacuum chamber is briefly described.

I. Used Formula and Beam Parameters

The Synchrotron Radiation power was calculated for Arcs 6 through 10 of the CEBAF 12 GeV Upgrade. The beam energy for Arcs 6-10 was E_6=6.6625 GeV, E_7=7.7525 GeV, E_8=8.8425 GeV, E_9=9.9325 GeV, and E_{10}=11.0225 GeV respectively. The SR power was calculated for a beam current of 100 μA for Arcs 6-9 and for a beam current of 5 μA for the 10th Arc. The SR power per unit length was calculated as

$$\frac{dP}{dL}(W/m) = 8.85 \cdot 10^4 \frac{E^4(GeV)\cdot I(A)}{2\pi\cdot\rho^2(m)}, \qquad (1)$$

where ρ is the bend radius.

II. Calculated SR Power

Table I shows the power of SR per unit length for 12 GeV Upgrade magnets. The table also shows the field and the bend radius of corresponding magnets.

Table I: SR power per unit length calculated according to (1).

Dipole	*B (kG)*	*Bend radius (m)*	*Radiation Power Loading (W/m)*
Arc 6 (beam energy = 6.6625 GeV, beam current = 100 μA)			
MAW6S01	14.3945	15.439	11.643
MAX6S02	11.8202	18.802	7.851
MAU6S03(*2m*)	-13.1303	16.926	9.687
MAB6S04	13.3208	16.684	9.970
MAB6S06	-13.3208	16.684	9.970
MBY6E01	-9.33064	23.818	4.892
MBZ6E02(*2m*)	9.33064	23.818	4.892
MBY6E03	-9.33064	23.818	4.892
MBB6A01-32(*2m*)	10.9055	20.378	6.683
MAB6R01	-13.3208	16.684	9.970
MAB6R03	13.3208	16.684	9.970

MAU6R04(*2m*)	-13.1303	16.926	9.687
MAX6R05	11.8202	18.802	7.851
MAW6R06	14.3945	15.439	11.643
Arc 7 (beam energy = 7.7525 GeV, beam current = 100 μA)			
MAQ1S01	12.8911	20.060	12.644
MAS3S02	11.9001	21.731	10.774
MYR7S03(*3m*)	-8.26371	31.293	5.196
MAC7S04	7.0686	36.584	3.801
MAC7S06	-7.0686	36.584	3.801
MBY7E01	-10.857	23.818	8.969
MBZ7E02(*2m*)	10.857	23.818	8.969
MBY7E03	-10.857	23.818	8.969
MBA7A01-32(*3m*)	8.45967	30.568	5.445
MAC7R06	-7.0686	36.584	3.801
MAC7R04	7.0686	36.584	3.801
MYR7R03(*3m*)	-8.26371	31.293	5.196
MAS3R02	11.9001	21.731	10.774
MAQ1R01	12.8911	20.060	12.644
Arc 8 (beam energy = 8.8425 GeV, beam current = 100 μA)			
MAW8S01	14.3943	20.491	20.509
MAX8S02	11.82	24.954	13.829
MYR8S03(*2m*)	-13.1072	22.503	17.005
MAE8S04	12.4133	23.761	15.252
MAE8S06	-12.4133	23.761	15.252
MBY8E01	-12.3834	23.818	15.179
MBZ8E02(*2m*)	12.3834	23.818	15.179
MBY8E03	-12.3834	23.818	15.179
MBA8A01-32(*3m*)	9.64902	30.568	9.216
MAE8R01	-12.4133	23.761	15.252
MAE8R03	12.4133	23.761	15.252
MYR8R04(*2m*)	-13.1072	22.503	17.005
MAX8R05	11.82	24.954	13.829
MAW8R06	14.3943	20.491	20.509
Arc 9 (beam energy = 9.9325 GeV, beam current = 100 μA)			
MAQ1S01	12.8911	25.701	20.754
MAS3S02	11.9001	27.841	17.686
MYR7S03(*3m*)	-8.26371	40.092	8.529
MYR9S04(*2m*)	-4.9191	67.351	3.022
MAR9S06	9.83929	33.694	12.075
MBY9E01	-13.9098	23.818	24.165
MBZ9E02(*2m*)	13.9098	23.818	24.165
MBY9E03	-13.9098	23.818	24.165
MBA9A01-32(*3m*)	10.8384	30.568	14.671
MAR9R06	9.83929	33.694	12.075
MYR9R04(*2m*)	-4.9191	67.351	3.022

MYR7R03(*3m*)	-8.26371	40.092	8.529
MAS3R02	11.9001	27.841	17.686
MAQ1R01	12.8911	25.701	20.754
Arc 10 (beam energy = 11.0225 GeV, beam current = 5 μA)			
MAW2S01	14.3963	25.539	1.594
MAX4S02	11.8303	31.079	1.076
MYR8S03(*2m*)	-13.1133	28.038	1.322
MYRAS04(*2m*)	-13.1133	28.038	1.322
MAYAS05	11.8303	31.079	1.076
MAHAS06	14.3963	25.539	1.594
MBYAE01	15.4362	23.819	1.832
MBZAE02(*2m*)	-15.4362	23.819	1.832
MBYAE03	15.4362	23.819	1.832
MBAAA01-32(*4m*)	9.02079	40.758	0.626
MAHAR06	14.3963	25.539	1.594
MAYAR05	11.8303	31.079	1.076
MYRAR04(*2m*)	-13.1133	28.038	1.322
MYR8R03(*2m*)	-13.1133	28.038	1.322
MAX4R02	11.8303	31.079	1.076
MAW2R01	14.3963	25.539	1.594
12 GeV beam line (beam energy = 12.1125 GeV, beam current = 5 μA)			
MAQ1S01	12.8911	31.342	1.543
MAS3S02	11.9001	33.952	1.315
MYR7S03(*3m*)	-8.26371	48.892	0.634
MYR7S04(*2m*)	-4.9191	82.136	0.225
MYRBS05(*2m*)	-5.63625	72.685	0.287
MARBS06(*2m*)	10.5548	38.280	1.034

Magnets MBY9E01, MBZ9E02, MBY9E03 of the 9th Arc radiate the highest power: 24 W/m. However, the SR power load per unit length can peak at spreader-recombiner magnets due to addition of the power radiated by the beam on different passes. One can expect a power load of approximately 40 W/m at magnets MAQ1S01, MAW2S01, and MAW2R06.

The total power of the SR at each arc and the average SR power per unit length are given in Table II.

Table II: Total SR power and average SR power per unit length at each Arc.

Beamline	*Average power per unit length of Arc (W/m)*	*Total radiation power (W)*
Arc 6	2.116	565
Arc 7	2.442	652
Arc 8	4.28	1143
Arc 9	6.25	1669
Arc 10 (5 μA)	0.407	108.7

12 GeV beamline (5 μA)		7.8

Notes on the Distribution of SR Power

b) The vertical size of the power distribution depends on the optical functions and the beam emittance at each magnet. The light track on the vacuum chamber will be larger than the beam size due to the divergence of the SR. Table III presents the minimum and maximum vertical beam sizes in Arcs 6-9 at the arc dipoles.

Table III: Vertical beam size at the arc dipoles and the vertical FWHH size of the light track on the vacuum chamber. The term $1.75 \cdot 10^6/\gamma$ is due to the divergence of SR (see next paragraph for more explanations).

Dipole magnets (Arc #)	Vert. Beam Size (FWHH) Min/Max (μm)	Light track FWHH Min/Max $+1.75 \cdot 10^6/\gamma$ (μm)
MBB6A01-32 (6)	120/450	250/575
MBA7A01-32 (7)	130/490	245/600
MBA8A01-32 (8)	145/550	250/650
MBA9A01-32 (9)	180/670	270/760
MBY9E01, MBZ9E02, MBY9E03 (9)	460/670	550/760

Note that the beam is bent vertically in the spreader/recombiner magnets. This yields a light track with a full width at half height of approximately 1.3 to 3.5 mm.

c) Because the radius of the outer wall of the vacuum chamber is larger than the radius of the beam trajectory, the synchrotron radiation hits the vacuum chamber some distance behind the point of the trajectory where the light was radiated from. Assuming that the vacuum chamber is circularly bent to follow the beam trajectory in a magnet, one can estimate the distance between the radiation and "landing" points as

$$d = \sqrt{2\rho a}\ ,$$

where a is the horizontal half-size of the vacuum chamber. For ρ=30.6 m (Arc 9 bending magnets) and a=5 cm, the distance d is 1.75 m.

d) A vacuum chamber transition from radius a_1 to a smaller radius a_2 will be accumulating the SR power radiated from a piece of trajectory of the length given by

$$\Delta d = \sqrt{2\rho a_1} - \sqrt{2\rho a_2}\ .$$

The power collected by this transition is given by

$$P_{trans} = \left(\frac{dP}{dL}\right)_{table1} \cdot \Delta d$$

For example, for a transition from a 4" pipe to a 2" pipe, the power accumulated by the transition is approximately 7.5 W.

e) If the vacuum chamber becomes straight right after a magnet, the power radiated from the last $d = \sqrt{2\rho a}$ meters of the beam trajectory, where a is the horizontal size of the straight section, will be distributed from the entrance of the straight section to the infinity (assuming that the straight section is infinitely long).

Comparison to VEPP-2M

The numbers obtained for the 12 GeV Upgrade can be compared to the SR power at VEPP-2M. VEPP-2M was a 350-650 MeV, e+e- collider located at Novosibirsk. For a beam energy of 510 MeV and a beam current of 50 mA, the radiated power per unit length of the beam trajectory within a magnet was 31.5 W/m (calculated from (1)). The average power per unit length of the vacuum chamber was 13 W/m. Normally, the vacuum chamber was water cooled. If water cooling was not applied, overheating of the vacuum chamber caused increased outgassing, which in turn would cause significant beam life reduction (by a factor of a few but less than an order of magnitude) and other effects related to a low residual vacuum (accumulation of ions, increased radiation background, etc.). Vacuum chamber overheating also caused damages to sensitive parts attached to the vacuum chamber such as plastic scintillators, coils, cables, etc. The character of damages indicated that the temperature of the outer surface of the vacuum chamber was around 100° C.

The power per unit length radiated at 12 GeV Upgrade is approximately the same or smaller than the SR power at VEPP-2M. However, it is important to note that VEPP-2M vacuum chamber was aluminum, while the CEBAF chamber is made of stainless steel. This can make the CEBAF vacuum chamber hotter in some areas for the same deposited power. Also note that the CEBAF beam passes each arc only once that makes the beam parameters less sensitive to the vacuum.

Conclusions

The SR power per unit length reaches 24 W/m at magnets MBY9E01, MBZ9E02, and MBY9E03. In the arc magnets MBA9A01-32 of Arc 9, the SR power per unit length is 15 W/m. Because the beam passes through spreader-recombiner magnets several times, the SR power can add up to approximately 40 W/m at magnets MAQ1S01, MAW2S01, and MAW2R06.

The average SR power per unit length of Arc 9 is approximately equal to 6 W/m. The total power radiated in Arc 9 is approximately equal to 1.7 kW.

The vertical size (FWHH) of the light track on the vacuum chamber at Arcs changes from approx. 0.3 mm to 0.76 mm. In spreaders and recombiners, the light track width is roughly 1.3-3.5 mm.

Transitions inside the vacuum chamber will lead to a redistribution of the power deposited on the walls of the chamber. Transitions from a larger radius to a smaller one will tend to get more power than other parts. However, this power cannot be much larger than 10 W.

A comparison of the SR power in Arc 10 of the CEBAF 12 GeV Upgrade and VEPP-2M indicate that the temperature of the CEBAF vacuum chamber can get high enough to damage sensitive plastic and rubber parts and cause additional outgassing and vaccum spoilage at high-number arcs.