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TITLE: SYNCHROTRON RADIATION POWER CALCULATIONS
AND BENDING RADIUS CHOICE FOR LER

Introduction

This note will discuss ways of choosing a bending radius and synchrotron radiation absorber design. We would like to decrease the synchrotron radiation power density on the absorber's surfaces, yet we would like to reduce the LER's bending radius for better matching with the HER (beam-beam interaction criteria [1]). We will consider two cases, both based on the PEP structure. One with 96 periods, containing 1 bending magnet per period and the other 2 bends per period. The case of synchrotron radiation absorbers outside of the bending magnet will be considered also.

Basic LER Parameters

To allow for future flexibility it seems reasonable to design LER for at least 4 GeV energy. We take this number as a worse case scenario for the synchrotron radiation power.

We are designing LER for a 3 Amp maximum average beam current, which yields the maximum synchrotron radiation power to be absorbed.

We took 3 cm minimum beam-wall distance, which corresponds to the 1 cm maximum horizontal displacement of the closed orbit from the axis of ± 3.9 cm by ± 2.4 cm vacuum chamber [2].

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We consider here a scheme in which the low-energy ring has the same circumference as PEP, and the same number of cells, but with either two or one bending magnets per cell (see Fig 1a/1b).

Synchrotron Radiation Power Density Distribution Along The Vacuum Chambers Wall for LER

We shall now examine the synchrotron radiation linear power density distribution along the wall of the vacuum chamber both inside the bending magnet (curved chamber) and the straight vacuum chamber sections (see Fig. 2). Here ρ = the bending radius, r = closest distance of the beam to the wall, φ = angle between the synchrotron radiation light and the wall of the straight vacuum chamber, L = the distance between the edge of the bending magnet and the place on the straight vacuum chambers wall, in this case the incident angle of the synchrotron radiation light is equal to φ :

$$L = \frac{r \cos \varphi - \rho (1 - \cos \varphi)}{\sin \varphi} \approx \frac{r}{\varphi} - \frac{\rho \varphi}{2}, \quad (\varphi \ll 1), \quad (1)$$

ℓ is the path length of the synchrotron radiation light:

$$\ell = \rho \tan \varphi + \frac{1}{\sin \varphi} \left(r - \rho \frac{(1 - \cos \varphi)}{\cos \varphi} \right) \approx \frac{r}{\varphi} + \frac{\rho \varphi}{2}, \quad (\varphi \ll 1). \quad (2)$$

The synchrotron radiation power production rate per unit length is estimated as follows:

$$P_{\text{prod.}} \left(\frac{\text{W}}{\text{cm}} \right) = \frac{E_{\text{los}} \cdot I}{2\pi \rho \ell} = 141.1 \frac{E^4 (\text{GeV}) I (\text{A})}{\rho^2 (\text{m})}, \quad (3)$$

where E_{los} is the energy loss of an electron per turn, I is the average beam current, ρ is the bending radius, and E is the electrons energy.

The variation of the synchrotron radiation linear power density along the wall of the vacuum chamber is shown in Fig. 3.

We should note, that there is a maximum angle $\varphi(\varphi_{\text{max}})$ (see Fig. 2) from which the synchrotron radiation light comes out of the magnet, and at the same time φ_{max} multiplied by

ρ is equal to the synchrotron radiation free distance at the beginning of the magnet (see Fig. 3).

$$\varphi_{\max} = \arctan\left(\frac{\sqrt{\gamma(\gamma+2\rho)}}{\rho}\right) \approx \sqrt{\frac{2\gamma}{\rho}}, \quad (\varphi \ll 1). \quad (4)$$

The maximum synchrotron radiation linear power density inside the bending magnet (see Fig. 3) is equal to:

$$P_{\max} = P_{\text{prod.}} \frac{\rho}{\rho+\gamma} \approx P_{\text{prod.}}, \quad (\gamma \ll \rho). \quad (5)$$

When we calculate the linear synchrotron radiation power density distribution along the wall of the straight vacuum chamber (see Fig. 3), we have to take into account a geometrical factor:

$$P(L) = P_{\max} K(L) \approx P_{\text{prod.}} K(L), \quad (\gamma \ll \rho), \quad (6)$$

where $K(L)$ is the geometrical factor in question. It is best to express K, L and l as functions of φ (see Fig. 2), then:

$$K(\varphi) = \frac{\rho \sin^2 \varphi}{\gamma + \rho(1 - \cos \varphi)} \approx \frac{1}{\frac{1}{2} + \frac{\gamma}{\rho \varphi^2}}, \quad (\varphi \ll 1). \quad (7)$$

Using equations (6), (7) and (1) for $(\varphi \ll 1)$ one can obtain the dependence of the linear synchrotron radiation power density upon the distance L along the straight section ($L = 0$ at the right edge of the bend):

$$P\left(\frac{W}{cm}\right) = 141.1 \frac{\mathcal{E}^4(\text{GeV}) I(A)}{\frac{\rho^2}{2} + \frac{\gamma \rho^3}{2(L^2 + \rho^2 - L\sqrt{L^2 + 2\rho\gamma})}}, \quad (\varphi_B \ll 1), \quad (8)$$

where φ_B is the bending angle per magnet, and ρ, r, L are expressed in meters.

It should be noted, that synchrotron radiation light cannot reach the bending magnets edge, if the bending angle is less than $\varphi_{\max}$ (see Fig. 2), and the corresponding L in Eq. (8) is not less than:

$$L_{\text{limit}} = \frac{\gamma}{\varphi_B} - \frac{\rho \varphi_B}{2}, \quad (\varphi_B \ll 1, \quad \varphi_B < \varphi_{\max}). \quad (9)$$

$P_{\max}$ is independent of r unless $\varphi_B > \varphi_{\max}$ (see Eq. (4)), (then synchrotron radiation strikes within the bends). But for short bends where $(\varphi_B < \varphi_{\max})$ synchrotron radiation does not strike within the bends, and $P_{\max}$ has a strong dependence upon the beam-wall distance r .

The synchrotron radiation linear power density distribution along the wall of the vacuum chamber is shown in Fig. 4. The curves that are plotted correspond to different bending radii ($L = 0$ at the right edge of the bending magnet). This is the case using two bends per cell (total number of bends is equal to 192).

Figure 5 shows the results using one bend per cell (96 bends per a turn). Summarized picture is shown in Fig. 6. Here P_{max} is the maximum synchrotron radiation linear power density and ρ is the bending radius. Both using 192 on 96 bends is of little significance bending radii of more than 56 m. In both cases the maximum power density is reached inside the bending magnets and is approximately the same. When the bending radii lie between 56 m and 14 m the situation changes. In this regime, synchrotron radiation light is emitted from the 192 bending magnets and remains inside for the 96 bends case. For bending radii less than 14 m, synchrotron radiation light does not strike the wall within the bend magnets.

Now we can determine the lowest limit of ρ , which corresponds to the maximum value acceptable for synchrotron radiation linear power - 10 kW/m (PEP value) for the worst case.

And the damping time: $\left\{ \begin{array}{l} \rho \geq 27.84 \text{ m (for 192 bends, } E = 4 \text{ GeV, } I = 3 \text{ A, } \gamma = 3 \text{ cm.)} \\ \rho \geq 34.16 \text{ m (for 96 bends, } E = 4 \text{ GeV, } I = 3 \text{ A, } \gamma = 3 \text{ cm.)} \\ T_{damp} \geq 72 \text{ ns (for 192 bends, } E = 4 \text{ GeV, } \rho \geq 27.84 \text{ m)} \\ T_{damp} \geq 89 \text{ ns (for 96 bends, } E = 4 \text{ GeV, } \rho \geq 34.16 \text{ m)} \end{array} \right.$

As can be seen the difference between the two cases is small.

$\left\{ \begin{array}{l} T_{damp} \geq 155 \text{ ns (for 192 bends, } E = 3.1 \text{ GeV, } \rho \geq 27.84 \text{ m)} \\ T_{damp} \geq 191 \text{ ns (for 96 bends, } E = 3.1 \text{ GeV, } \rho \geq 34.16 \text{ m)} \end{array} \right.$

Synchrotron Radiation Linear Power Distribution Along the Vacuum Chambers Wall for HER

Similar calculations have been done for HER, as in the previous case, we took the worst parameters for synchrotron radiation power.

$$E = 9 \text{ GeV}$$

$$I = 3 \text{ A}$$

$$\gamma = 3 \text{ cm}$$

additionally we took into account the precise dependence of the synchrotron radiation linear power at the beginning of the bending magnet (see Fig. 7). It should be noted this synchrotron radiation comes from the preceding magnet.

Here L_0 = the length of the straight section, ρ = the bending radius, r = the closest distance of the beam to the wall, φ_0 = the maximum angle, at which the synchrotron radiation light of

the preceding magnet enters the next magnet, φ is the angle, which the synchrotron radiation light of the preceding magnet strikes the next magnet's vacuum chamber wall, along the distance L from the beginning of the next magnet (see Fig. 7), φ_i is equal to $L/\rho, \varphi_{max}$ - see (4).

The synchrotron radiation linear power at the beginning of the bend is determined as follows:

$$P = P_{prod} \cdot \frac{\rho}{\rho + r} \left| \frac{d\varphi}{d\varphi_i} \right| = K P_{prod}. \quad (10)$$

where P_{prod} = the synchrotron radiation power production rate per unit length (W/cm), k = the geometrical coefficient. For precise expressions it is more suitable to use a parametrical representation: $\left| \frac{d\varphi}{d\varphi_i} \right| = \frac{1}{1 + \frac{L_c \cos \varphi}{(\rho + r) \sqrt{1 - \frac{(L_c \sin \varphi + \rho)^2}{(\rho + r)^2}}}}$, $L = (\rho + r)(\arccos \{ \frac{L_c \sin \varphi + \rho}{\rho + r} \} - \varphi)$, $0 \leq \varphi \leq \varphi_0$, where $\varphi_0 = \arcsin \left\{ \frac{\sqrt{L_c^2 \rho^2 + (2\rho r + r^2)(L_c^2 + (\rho + r)^2)} - L_c \rho}{L_c^2 + (\rho + r)^2} \right\}$ (11)

Fig. 8 shows the dependence of the synchrotron radiation power on the distance to the vacuum chamber wall at the beginning of the next bending magnet ($L = 0$ at the left edge of the next bending magnet). The different curves correspond to the different beam-wall distances.

The bend length (5.4 m) and the distance between the bends ($L_0 = 1.67m$) always corresponds to PEP's regular values.

Fig. 9 is like Fig. 8, but all curves have the same beam-wall distance ($r = 6$ cm), and varying distance between the bends. The bending radius and bending angle are fixed and always corresponds to PEP's ($\rho = 165$ m, $\varphi_B = \frac{2\pi}{192}$.)

The distribution of the synchrotron radiation linear power along the HER lattice is represented in Fig. 10.

Curves plotted for different beam-wall distances, but for the same energy ($E = 9$ GeV), beam current ($I = 3A$), bending radius ($\rho = 165$ m), and lattice geometry, ie. PEP's. For conservative vacuum chamber design, the upper curves should be used.

Synchrotron Radiation Heating of the Discrete Absorbers Crotch

The final part of our paper is devoted to the discrete synchrotron radiation absorber outside of the bending magnet. We will examine the possibility of the bending radius reduction in LER, using localized synchrotron radiation absorbers.

Basically the main difficulties of this approach are:

- 1) Crotch heating by synchrotron radiation
- 2) Crotch heating by coherent RF radiation of bunches
- 3) Additional impedance of the absorber's gaps.

In this paper we will discuss only the first item. The next two items require additional consideration.

Geometry of the discrete synchrotron radiation absorber is represented in Fig. 11.

where ρ = the bending radius, L = the longitudinal size of the absorbers gap, l = the path length of the photons, which are absorbed on the crotch, φ_1 = the crotch angle.

For our calculations we will use the synchrotron radiation power density on the crotch surface in W per cm^2 . We assume that the electron beam has zero vertical size, and synchrotron radiation beam has a natural divergence $\approx 1/\gamma$. This gives the maximum power density on the crotch surface: $P_i \left(\frac{W}{cm^2} \right) = 2822 \cdot \frac{E^5 (GeV) I (A)}{\rho^2 (m) \ell (m)} \cdot \frac{\rho \sin \varphi_1}{\gamma (m) \rho (1 - \cos \varphi_1)}$, compare with (6) and (7),
 $\ell = \rho \tan \varphi_1 + \frac{1}{\sin \varphi_1} \left(\gamma - \rho \frac{(1 - \cos \varphi_1)}{\cos \varphi_1} \right)$, $L = \frac{\gamma \cos \varphi_1 - \rho (1 - \cos \varphi_1)}{\sin \varphi_1}$, (ρ, γ, ℓ, L - meters).

Fig. 12 shows the dependence of the maximum upon l for different bending radii power density for LER with ($E = GeV$, $I = 3A$) on the crotch surface. The beam-wall distance is fixed and equal to 3 cm.

Fig. 13 is like Fig. 12, but the beam wall distance equal to 6 cm.

At the small bending radii region (from 10 m to 30 m) the main power is absorbed in approximately the fifth meter region from the edge of the bending magnet. As a result we have to use approximately 5 meter long synchrotron radiation absorber gap, and at the same time we will have a serious problem with crotch synchrotron radiation heating ($10 kW/cm^2$). It is 20 times more than PEP's maximum value ($\approx 500 W/cm^2$). This high power density can be reduced by using a sloping wall, but in this case it is necessary to calculate carefully the absorbed and reflected parts of the total synchrotron radiation power striking the crotch surface. In

PEP synchrotron radiation strikes at a very small angle and a significant part of the synchrotron radiation energy is reflected.

REFERENCES

1. Investigation of an Asymmetric B Factor in the PEP Tunnel, LBL-PUB-5263, SLAC-PUB-359, CALT-68-1622, March 1990.
2. Sizing the Vacuum Chambers Conservatively, A. Hutton SLAC/LBL ABC-6, March 21, 1990.

a)

b)

Fig. 1

Fig. 2

Fig. 2

Fig. 3

Fig. 4

$E=4\text{ GeV}$, $I=3\text{ A}$, $NB=192$, $r=3\text{ cm}$

Fig. 5

$E=4\text{ GeV}$, $I=3\text{ A}$, $NB=96$, $r=3\text{ cm}$

Fig. 6

Fig. 7.

Fig. 8

$L_0 = 1.667 \text{ m}$, $\rho = 165 \text{ m}$ $N_8 = 192$ (HER)

Fig. 9.

Fig. 10

$E=9\text{GeV}$, $I=3\text{A}$, $\rho=165\text{m}$, $L_0=1.67\text{m}$

Fig. 11.

$E = 4 \text{ GeV}, I = 3 \text{ A}, r = 3 \text{ cm}.$

Fig. 12

$E = 4 \text{ GeV}, I = 3 \text{ A}, r = 5 \text{ cm}.$

Fig. 13.

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