PHY 554 Mid-term exam 10/26/26

Problem 1. (40 pts)

NSLS-II is a third-generation light source, which adopts double bend achromat (DBA) lattice (illustrated in Figure. 1)

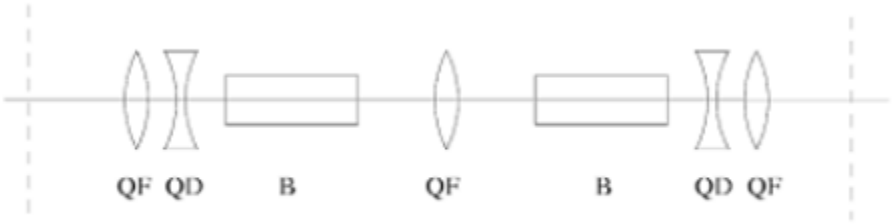


Figure 1: DBA lattice

The parameters for NSLS-II is given in the table

Table 1: NSLS II parameters

Parameters	Values
Energy [GeV]	3.0
Circumference [m]	780
Number of dipoles	60
Dipole field [T]	0.4
Beam current [A]	0.5
RF frequency [MHz]	499.68
Harmonic number	1320

Use the table and plot, answer following questions:

1). Find the length of the dipoles assuming they are all identical. (5 pts)

2). In the DBA lattice, dispersion D and D' are zero at both ends. Write down the expression of the dispersion function inside the dipole magnets. (10 pts)

3). Calculate the momentum compaction factor $\alpha_c = \frac{1}{C}\oint \frac{D(s)}{\rho} ds$ of the ring. (5 pts)

4). Assuming that at the center of outer straight section (s=0, dashed line in the plot), the lattice is symmetric, meaning the horizontal alpha function $\alpha_0 = 0$ and the horizontal beta function is β_0. Write down the beta function at the entrance of the first quadrupole's (QF in the plot) location (s=Ld). (10 pts)

5). Find the value of β_0 to minimize the beta function at the start of the QF. (5pts)

Problem 2. (25 pts)

Consider operating the NSLS-II's RF system at peak voltage of Vrf = 1.2 MV and it is known that the energy loss per turn due to synchrotron radiation is U0 = 600 keV per electron.

Answer following questions:

1). Calculate the phase slippage factor η. (5 pts)

2). Calculate the synchronous phase φ_s needed to compensate the synchrotron radiation loss (use the convention where $\varphi_s = 0$ represents zero acceleration). (5 pts)

3). Calculate the synchrotron tune Q_s. (10 pts)

4). Calculate the synchrotron frequency f_s (in Hz). (5 pts)

Problem 3. (35 pts)

A cylindrical superconducting RF pillbox cavity of length L = 0.3 m operates in the fundamental accelerating TM010 mode at frequency f = 500 MHz. The peak on-axis accelerating electric field is E0 = 20 MV/m. Assume vacuum inside the cavity.

(a) **Cavity radius and stored energy** (15 pts)
   1. Determine the cavity radius a from its resonant frequency. (5 pts)
   2. Calculate the total electromagnetic energy W stored in the cavity. Does W vary with time in the ideal lossless cavity? (10 pts)

(b) **RF power loss** (10 pts). The cavity has a uniform RF surface resistance Rs = 5 nΩ. Calculate the time-averaged power lost in the cavity walls, including both the cylindrical wall and both circular end plates.

(c) **Intrinsic quality factor** (10 pts). Calculate the intrinsic quality factor Q0.

Useful information. In SI units the fields for the TM_{010} mode may be written as

$$E_z(r,t) = E_0 J_0\left(\frac{\chi_{01} r}{a}\right)\cos(\omega t),$$
$$H_\phi(r,t) = \frac{E_0}{Z_0} J_1\left(\frac{\chi_{01} r}{a}\right)\sin(\omega t),$$

where $\chi_{01} = 2.4048$ is the first positive zero of J_0, $\omega = 2\pi f$, and $Z_0 = \sqrt{\mu_0/\epsilon_0} \simeq 376.73\,\Omega$. You may use

$$\int_0^1 J_0^2(\chi_{01}x)\,x\,dx = \int_0^1 J_1^2(\chi_{01}x)\,x\,dx = 0.134757,$$
$$J_1(\chi_{01}) = 0.519147, \qquad c = 2.997\,924\,58 \times 10^8\ \mathrm{m/s},$$
$$\epsilon_0 = 8.854\,187\,8 \times 10^{-12}\ \mathrm{F/m}, \qquad \mu_0 = 4\pi \times 10^{-7}\ \mathrm{H/m}.$$