Calculation of parameters for HF station of the storage ring DELSY

JINR Summer Student Programme project report

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Abstract

DELSY accelerator complex is designed as a SR source of 1.2 GeV energy electrons. It consists of an electronic linear accelerator, an injection channel, a storage ring and 10-12 channels of synchrotron radiation.

INTRODUCTION

The electron beam is injected from the linear accelerator [1] to the storage ring of DELSY, at the energy of electrons 800 MeV and injection current of 5-10 mA. The injection pulse repetition frequency is determined by the radiative damping of betatron oscillations and is about 10 Hz. As a result of the accumulation it is planned to get an electron beam with a current of 300 mA. After accumulation, electrons are accelerated from 0.8 GeV to 1.2 GeV in the synchrotron mode. The lifetime of the electron beam in the multi bunch mode at the energy of 1.2 GeV varies from 5 to 10 hours, depending on its parameters. In this mode DELSY used as a source of SR. After a session with duration of several hours the cycle of the accelerator complex repeats.

In DELSY project a linear accelerator with the length of 200 m, will be located in an existing building N118 on the LNP territory (Figure 1.1.). The injection channel from the linear accelerator to storage ring DELSY is designed to take into account the existing magnets of NIKHEF complex [2]. Its structure is also determined by the interposition of the N118 building and the storage ring tunnel.

The magnetic structure of the electron ring DELSY is noticeably changed from AmPS [3]. The perimeter of the storage ring is reduced 1.5 times. The new magnetic structure in usine allows to decrease the beam emittance in DELSY by the order of magnitude in comparison with AmPS. It is expected to get electron beam with emittance of 11 nm at 1.2 GeV electron energy in DELSY. A tunnel for storage ring, as well as buildings for SR channel and experimental stations (Figure 1.1.) will be built next to the N118 building.

In DELSY, to achieve luminance of SR about 10^{18} photons/sec/mm^2/ mrad^2/0.1% sh.p. it is planed to install a mini-onduler, which generates synchrotron radiation with energy of photons 150eV-3keV. For the generation of hard X-rays with photon energies of 20-50keV the ring will be equipped with a superconducting wiggler with magnetic field with magnitude of 10T.

For users of the SR it is expected to build 6-8 channels of synchrotron radiation using bending magnets, operating in the infrared, visible, ultraviolet, as well as in the soft X-ray regions. The 6-8 stations will be set up on the SR channels from wiggler and 3-4 stations will work on the SR of the onduler.

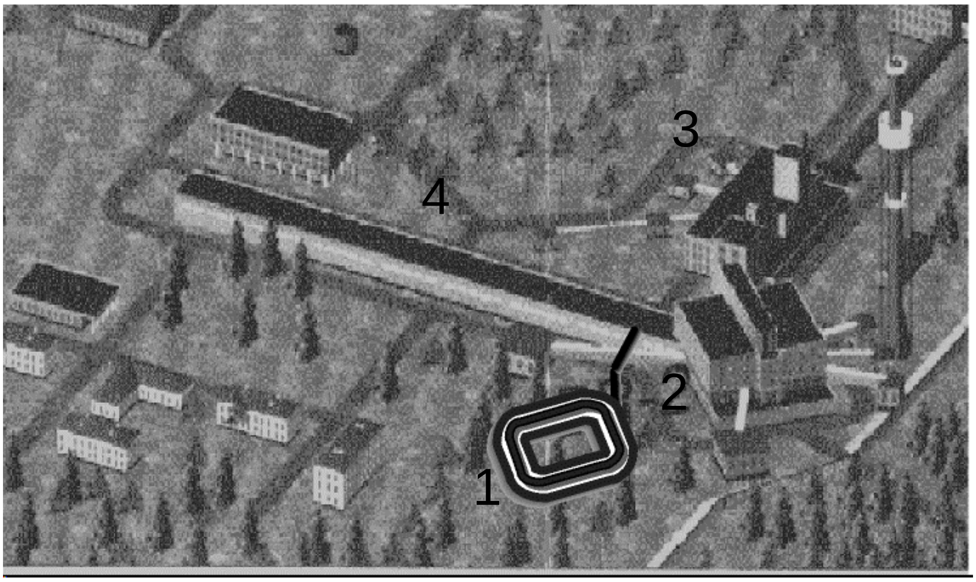

Figure 1.1. The layout of the DELSY complex on the territory of JINR. 1. electronic storage, 2 –IBR-2, 3 –IBR-30, 4 - №118 building (linear accelerator DELSY).

HF stations of DELSY storage ring

The calculations and parameters of HF stations of DELSY

It is planned to have two HF stations in the storage ring (Table. 1.1.), one of which operates at 476 MHz (Figure 1.2.) [4], and the other one at the frequency of linear accelerator 2856 MHz (Figure 1.3.). [5- 6].

Table 1.1. Parameters of HF-stations and electron beam of DELSY storage.

Energy of electrons, GeV	0.7	1.2
Frequency, MHz	2856	476
The maximum voltage, kV	130	350
Number of harmonic	1122	223
Klystron power, kW	50	30
Shunt resistance, MOhm	12.8	4.5
Quality factor	1260	4000
Filling time, ns	19	
Equilibrium dispersion on energy, %	$3.3\cdot10^{-2}$	$5.7\cdot10^{-2}$
The length of the bunch, mm	2.6	8.67
The frequency of synchrotron oscillations	0.013	0.007
Energy loss, keV/turn	6.4	55.7

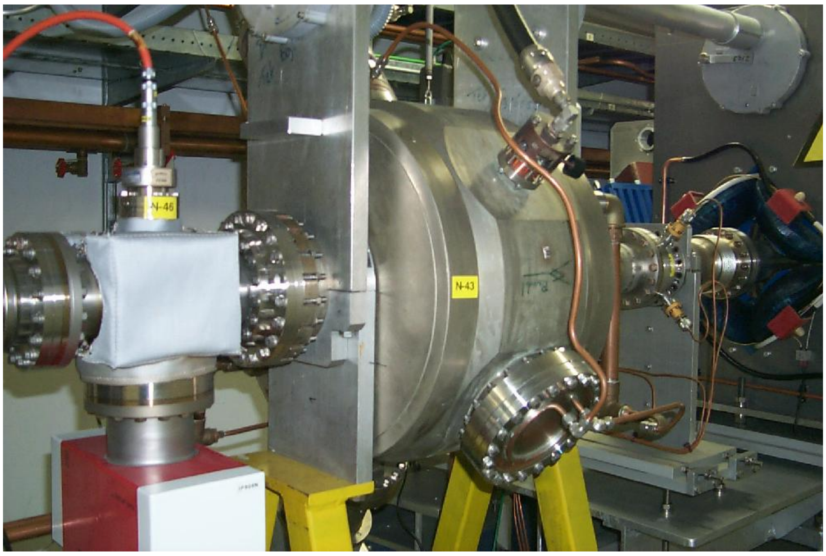

Fig. 1.2. The HF-station at the frequency of 476 MHz.

The Dependence of power of HF-station on HF-voltage is determined by the relation:

$$P_{RF} = \frac{V_{RF}^{\ 2}}{R} \frac{\tau_x^{\ 2}}{4(1-e^{-\tau_x})^2} \quad , \qquad \tau_x = \frac{f_{RF} T_f}{2Q} \quad , \qquad (1.1)$$

where V_{RF} is the HF-voltage, f_{RF} - the HF-frequency, R - the shunt resistance, Q - the quality factor, T_{RF} - the filling time of HF-station.

Fig. 1.3. HF station at the frequency of 2856 MHz.

The size of RF separatrix (the maximum energy spread of the electrons trapped in the RF) (Figure1.4.), is:

$$\sigma_b = \frac{\Delta E}{E} = \sqrt{-\frac{V_{RF}}{h\alpha E}\left[\frac{2}{\pi}\cos\varphi_s - \left(1-\frac{2}{\pi}\varphi_s\right)\sin\varphi_s\right]}, \qquad (1.2)$$

where E is the energy of the electron, h- the harmonic number, α- the orbit expansion coefficient, φ_S- the equilibrium phase:

$$\varphi_s = \pi - \arcsin\frac{U_0}{V_{RF}}, \qquad (1.3)$$

here the U_0 energy lost by the electron per revolution is :

$$U_{0[KeV/turn]} = 88.5 \cdot E_{[geV]} / R_{[m]}. \qquad (1.4)$$

Here R is radius of bending magnets of the storage ring.

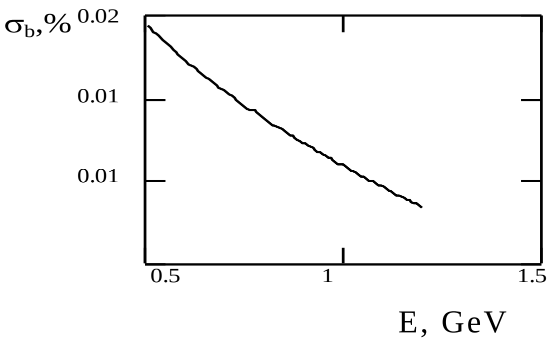

Fig. 1.4. The dependence of the size of the RF separatrixes from the energy of electrons, V_{RF}=350 kV, f_{RF}=476 MHz.

The equilibrium energy spread (Figure 1.5.) is determined by quantum fluctuations, and is given as

$$\sigma_\varepsilon = \left(\frac{55}{32\sqrt{3}} \frac{\hbar}{mc} \gamma^2 \frac{I_3}{2I_2 + I_4} \right)^{1/2}, \qquad (1.5)$$

where I_2, I_3, I_4 are integrals of synchrotron radiation.

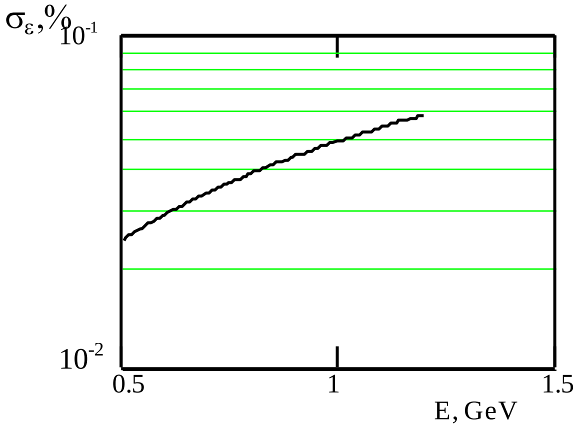

Fig. 1.5. The dependence of the equilibrium energy spread on the electron energy, V_{RF}=350 kV, f_{RF}=476 MHz.

The magnitude of the RF voltage is determined by the condition 8, 10-fold excess of HF energy size of separatrix above the equilibrium energy spread:

$$b \equiv \frac{\sigma_b}{\sigma_\varepsilon} \approx 8 - 10. \qquad (1.6)$$

The last determines the lifetime of the beam caused by quantum fluctuations,

$$\tau_{live} = \tau_\varepsilon \frac{e^x}{2x},$$

$$\tau_\varepsilon^{-1} = \frac{r_e c}{3} \frac{\gamma^3}{C_e} (2I_2 + I_4), \qquad x = \sigma_b^2 / 2\sigma_\varepsilon^2 \equiv b^2/2. \qquad (1.7)$$

Here r_e the classical electron radius, C_e– the perimeter storage ring. For HF-station on the frequency of 476 MHz, and HF-voltage of 350 kV, the value of parameter b> 10 (Fig. 1.6.) for all electron energies below 1.4 GeV, thus avoiding the limitations of the beam lifetime due to quantum fluctuations.

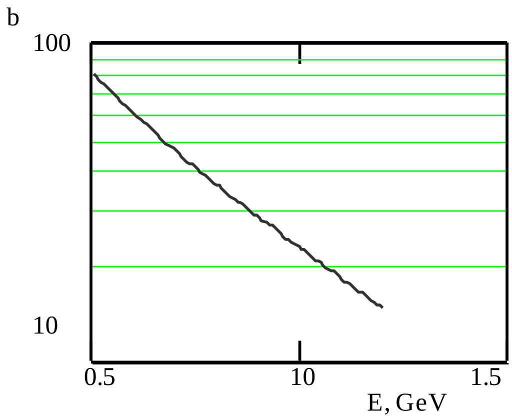

Fig.1.6.The dependence of the parameter b on the electron energy, V_{RF}=350 kV, f_{RF} = 476 MHz.

The length of the bunch, (which is determined by quantum fluctuations of SR) is:

$$\sigma_l = \alpha \frac{C_e}{2\pi} \frac{\sigma_\varepsilon}{\nu_s}, \qquad (1.8)$$

where ν_S is the synchrotron number (the ratio of the synchrotron oscillation frequency to the frequency of treatment):

$$\nu_s = \sqrt{-\frac{V_{RF} h \alpha \cos\varphi_s}{2\pi E}} \qquad (1.9)$$

For a beam of electrons with energy of 1.2 GeV and V_{RF} = 350 kV the value of σ_i is 8.67 mm and the frequency of synchrotron oscillations is 0.007.

The HF station at the frequency of 476 MHz (see. Section 1.2.) has a resonator made on the basis of a twin-toroidal resonator of the accelerator DESY (the operating frequency of 500 MHz). The generator with 30 KW power, on a klystron YK1233 produced by Philips, provides voltage in the gap of this resonator up to 400 kV. The station has the equipment for frequency, phase and amplitude auto-adjustment.

The HF-station operating on 2856 MHz frequency is intended for receiving super short bunches. However the 50 kW power of klystron and 130 kV voltage of HF-resonator are insufficient for provision mode of accumulation at the energies closed to 1.2 GeV. This station can only be effectively used in the energy range up to 0.5-0.7 GeV.

References

[1] Kroes F.B., "Electron Linac MEA" Linacs, LINAC96 Conference, Geneva, 22-29 August 1996.

[2] Internet: \\www.nikhef.nl\ .

[3] Wu Y., The optical design of AmPS, Doctor Thesis, Amsterdam,1991.

[4]. Kroes F.B., P.de Groen, Heine E. et al., A 476 MHz RF system for the storage mode of the AmPS ring, NIKHEF-K, Amsterdam, Netherlands.

[5] Kroes F.B. et al., A fast amplitude and phase modulated RF source for AmPS, Proc. of PAC'91, p.684.

[6] Maas R. et al., Commission results of the Amsterdam Pulse stretcher/storage ring, Proc. of PAC'93, p.1998.