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JINR TAU-CHARM FACTORY STUDY

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ABSTRACT

The tau-charm factory is a part of the designed JINR storage ring complex. The first design considerations were reported in /1,2/. The second variant of JINR tau-charm factory design differs from previous one mainly in the next features. The layout of the electron-positron storage ring complex on the JINR territory was changed. We have changed also the structure scheme of the injection complex and consider now multi-bunch injection regime instead of the first single-bunch regime operation to simplify the electron source and to exclude the damping ring from the design. The magnet lattice includes an only interaction point in this variant and the flat beam scheme is used.

Now hybrid variants of magnetic lattices for possible realization of flat beam and monochromatization schemes are widely discussed/3,4/. A variant is being under consideration at JINR with changing of the emittance of the colliding beams and changing of the focusing fields in the micro-beta insertion/4/.

1 THE ELECTRON-POSITRON STORAGE RING COMPLEX LAYOUT, STRUCTURE SCHEME AND CYCLOGRAMS OF TAU-CHARM FACTORY

Two variants of the electron-positron storage ring complex disposals were studied at JINR. Now the third variant of storage ring complex disposed as the whole on the spare JINR territory (Fig.1) is under examination.

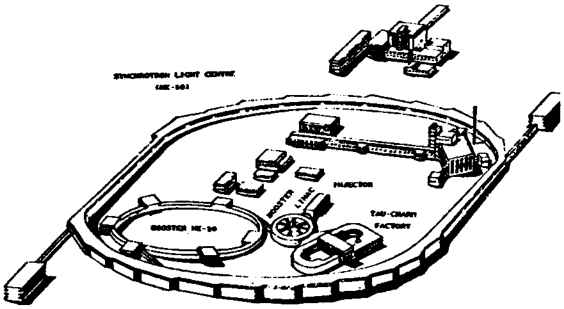

Fig.1 Layout of the JINR storage ring complex

The layout and structure scheme of the tau-charm factory with an injection complex and the main ring are shown in Fig.2.

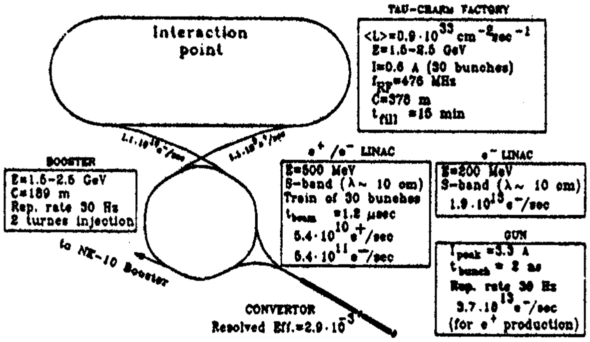

Fig.2. Layout and structure scheme of tau-charm factory.

The injection complex consists of a preinjector and a fast booster synchrotron. The preinjector is expected to be also used for initial acceleration of particles for NK-10.

The energy at the preinjector output is ≅ 500 MeV and the number of particles must be such that the simultaneous work of the tau-charm factory and the NK-10 ring could be ensured. The injection complex cyclogram: positron flux ($\dot{N}_{e+}$)(a) and luminosity (b) time dependencies are shown in Fig.3. The typical times for the electrons are much smaller.

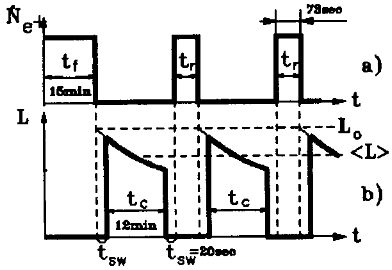

Fig. 3. The injection complex cyclogram: positron flux $\dot{N}_{e+}$ from the injection complex (a) and the luminosity variation (b).
t_f – the positron "full-fill" time;
t_r – the refilling time;
t_c – the counting time;
t_{sw} – the detector switch on/off time;
<L> – the average luminosity.

The average luminosity is ensured on the level of 80 % of peak luminosity. The beam lifetime τ is about 210 min and it is determined mainly by particle bremsstrahlung at the injection point. We suppose to obtain vacuum in the storage ring chamber at the level of $2 \cdot 10^{-9}$ Torr.

Due to switching time of the detector $t_{sw} \cong$ 20s the average luminosity has a maximum value for the detector counting time t_c = 12 min, that's enough for the refilling of particles in the NK-10.

The positron number in the tau-charm factory must be $4.8 \cdot 10^{12}$ for ensuring of the necessary luminosity value. Then taking in account that the transfer efficiency from the injection complex through the booster into the tau-charm factory is supposed to be 10%, and the filling time is chosen equal to 15 minutes we obtain that the productivity of the injection complex ought be $5.4\cdot10^{10}$ e^+/s. The positron production resolved efficiency is limited on the reasonable positron energy spread ≈ 1% and emittance acceptable by the booster and is estimated as 0.3%. Therefore the electron flux impinging the conversion target must be about $2\cdot10^{13}$ e^-/s. The bunching efficiency will be of the order of 50% and the whole electron flux from the gun must be of $3.7\cdot10^{13}$ e^-/s.

2 PREINJECTOR

The preinjector comprises two resonant travelling-wave linacs with the working frequency about 2856 MHz. One accelerator of energy 200 MeV is to produce positrons in the conversion target of tungsten and the other is to accelerate electrons and positrons up to 500 GeV. The expected positron emittance value is $3\cdot10^{-3}$ cm·rad, the energy spread is about 1% .The total length of the preinjector is about 40 m. Microwave power is supplied by klystron amplifiers, which ensure the accelerating gradient up to 25 MeV/m. The pulsed power at the accelerating section input is about 25 MW.

We suppose to use a quarter-wave transformer (QWT) in order to match the positron beam on the entrance of the second linac. The conversion efficiency will be refined in future designing.

The beam is produced by a grid-controlled gun. Together with the systems of subharmonic and working-frequency bunching, it provides a train of 30 (or 45) bunches with bunch spacing 42 ns, macropulse time duration 1.2 µs in the case of two-turn injection into the booster (1.85 µs-three-turn injection) and total charge 6.6 (4.4) nC. The peak current with micropulse length 2 ns is 3.3 (2.2) A. This operating mode of generating multibunch trains is repeated with the frequency 30 Hz.

3 BOOSTER

The booster synchrotron is designed as injector of the tau-charm factory. It will be used for acceleration of 500 MeV electrons and positrons injected from the preinjector up to the full energy of the tau-charm factory. Its perimeter of 189m allows to inject into the main ring, in a bunch to bunch, 15 bunches on a single turn. The problems connected with 2 or 3 turn injection into booster are under consideration. With the repetition rate 30 Hz the booster provides 0.6 A positron current to be stored in the tau-charm factory within about 15 minutes and the 10^{33} $cm^{-2}s^{-1}$ peak luminosity to be effectively maintained.

The magnetic structure of the booster consists of six superperiods, each containing six FODO-type cells. The hexagonal shape of the booster is determined by the disposition of the injection channels in the configuration chosen for the complex. Two long straight sections house injection devices, three others are for extraction to the injection channels of the tau-charm factory and the NK-10 booster. The sixth section houses an RF station.

Every superperiod consists of three standard FODO cells, two cells each containing one bending magnet - dispersion suppressors - and one straight section. The position of focusing and defocusing quadrupoles (QF,QD: $L=0.3m$, $B_{max}=k_1\cdot B\rho \cong 15T/m$), the H-type bending magnets (BM: $L=1.3m$, $B_{max}\cong 0.84T$), sextupoles (SD,SF: $L=0.15m$, $g_{s\,max}=K_2\cdot B\rho \cong {}_{1/2}B'' \cong 110T/m^2$) is shown in Fig.4.

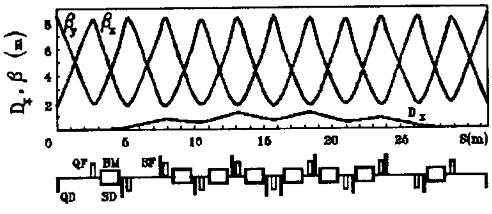

Fig.4. Lattice functions in the booster suprperiod.

The lattice functions for one super period are also shown in Fig.4 The horizontal and vertical beta functions (β_x, β_z) have extreme values of 1.8m and 8.5 m . In the "missing magnet" region the dispersion function of $D_x <$ 1mm, its maximum value elsewhere is $D_x=1.2m$. With a cell length of 5.25m and tunes of $Q_x=8.55$ and $Q_z=8.62$ a natural beam emittance of $\varepsilon_0=1.2\cdot10^{-7}$ m·rad is achieved.

Table 1

Beam energy (GeV)	2.5
Emittance(2.5 GeV) ε_0 (m.rad)	$1.2\cdot10^{-7}$
Nominal current I_{e^-}/I_{e^+} (mA)	6 / 0.6
Energy spread σ_E/E	$7\cdot10^{-4}$
Circumference (m)	189
Repetition rate (Hz)	30
Tunes Q_x/Q_z	8.55/8.62
Momentum compaction factor	0.0193
Bending radius ρ (m)	9.93
Damping times $\tau_x/\tau_z/\tau_s$ (msec)	9/9/4.5
Harmonic number	300
Energy loss/turn (MeV)	0.35
RF voltage (MV)	2.5

In order to correct chromaticities of $\xi_x = -10.6$ and $\xi_z = -10.4$ two different sextupole families (SF and SD) will be installed near the focusing and defocusing quadrupoles. To avoid a time varying sextupole component, created due to the rising magnet field /5/, we suppose to use nonmetallic vacuum chambers in the dipole magnets.

The main booster parameters are given in Table 1.

The booster synchrotron will make use of about 500 MHz RF system. Maximum RF voltage required for acceleration, synchrotron radiation loss compensation and obtaining of suitable longitudinal bunch size of σ_s is also given in Table 1.

4 MAIN RING

The electron-positron collider comprises two storage rings (see Fig.5), each with a perimeter of 377.8 m. They are 1.3 m vertically distanced. In the middle of 100 m straight section there is a place for an universal detector, which being designed in JINR now. Structurally combined with the detector there are micro-beta insertions (two superconducting triplets) installed symmetrically on the distances 0.8 m about the interaction point to make the vertical β-function be approximately 1 cm at this point. The gradient in the superconducting quadrupoles is about 30 T/m for maximum energy of particles 2.5 GeV. Two quadruples have the length 0.5 m, the third one - 0.2 m. The lattice functions at interaction region are shown in Fig.6.

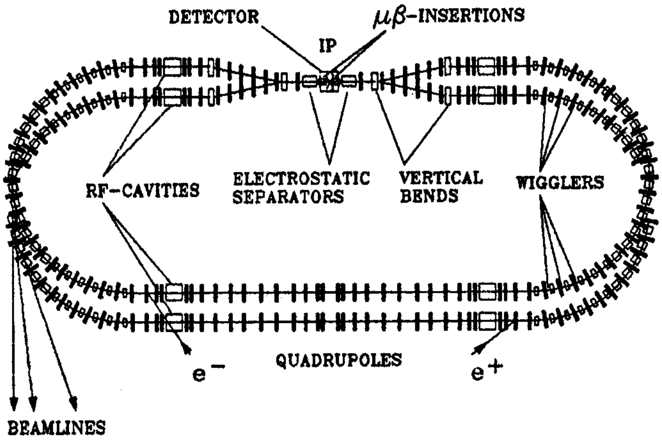

Fig.5. Tau-charm factory storage rings scheme.

The straight sections also house electrostatic separators, magnets of vertical deflection and beam separating lenses, injection devices, RF cavities to compensate synchrotron radiation losses and to maintain the longitudinal bunch dimension less than 1cm, and dipole wigglers for obtaining the necessary energy spread at energies below 2.2 GeV.

The electric field strength in the separator and the separator length are chosen to make the distance between the bunches about 12.6m. There are 30 bunches of each component in the ring. We have restricted for electric field strength by 2.5MV/m to avoid a breakdown, when a large beam current passes through the separator. The separator length was defined as 3.4m. These parameters of the separator give the vertical deflection at its outer edge of 5.8mm. The vertical beam size at this point is $\sigma_y \simeq 0.43$mm, so we have vertical bunch separation of 27 σ_y at parasitic interaction point.

The small value of vertical deflection angle $\theta \simeq 3.4$ mrad caused by electrostatic separator is insufficient for effective separation of the beams in two vertically distanced rings. We use additionally a warm lens Q4, placed after separator and have the vertical deflection on the entrance of the first vertical bend magnet about 40 mm. Another positive fact of using lens Q4 is the reducing of critical energy of radiated photons and as a result background decreasing at I.P. compared with those when there is vertical bend instead Q4. In our choice the maximum energy have the photons produced on the first vertical bend (critical energy - 0.5 KeV), the whole radiation power at I.P.region is estimated as 100 W. The lattice functions for vertical separation region are shown in Fig.7.

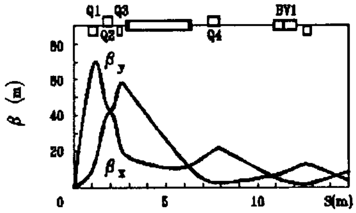

Fig. 6. Lattice functions in interaction region.

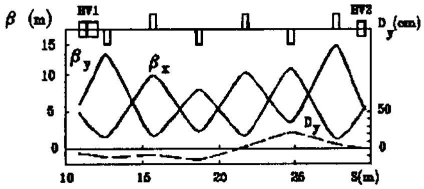

Fig.7. Lattice functions in slope region.

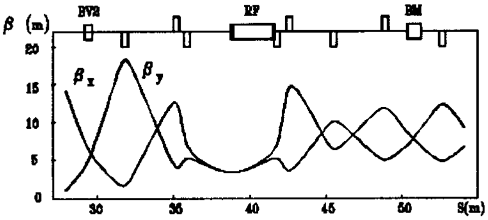

Fig.8. Lattice functions in RF cavities straight section.

For RF cavities straight section lattice functions are shown in Fig.8. To decrease beam interaction with transverse modes of RF cavities the β values were minimized by using of doublets.

The design of the tau-charm factory radio frequency system meets the strict requirements of providing single-bunch and multi-bunch stability of the beams. Superconducting cavities of a type as suggested for B-factory in CESR /6/ are planned to be used together with special measures for suppression of the modes higher than the basic one.

The radio frequency system for the tau-charm factory must compensate the particle energy losses arising from the synchrotron radiation and HOM excitation in RF-cavities (SR losses power is equal to 174 kW for particle energy 2.2 GeV). RF system consists of four super-conducting acceleration cavities (per one ring), which are placed at the ends of the long straight sections. Each cavity consists of three cells. The radio frequency is chosen equal to 476 MHz. It provides the single- and multi-bunch beam stabilities with the help of the feed back systems. The choice of this frequency also permits to maintain the necessary longitudinal bunch dimensions under achievable accelerating voltage in the superconducting cavities.

The longitudinal bunch size is equal to 7mm for the total RF-voltage amplitude about 18 MV.

Each arc of the tau-charm factory has 12 cells with periodicity of FODO type with a 60-degree phase gain in each. The regular part includes 6 cells with a bending angle of 10 deg. at each magnet, and two dispersion suppression sections, each containing 3 cells with a half bending angle at a magnet. In the dispersion suppression sections there are wigglers to adjust emittance. Using wigglers with magnetic field B=1.7 T and total length l_w= 5.2 m we can keep longitudinal beam size constant and emittance changing ~ E^2.

Chromaticity is corrected by two families of sextupole lenses arranged in a standard way. The dynamic aperture calculated for $\delta p=0$ with code MAD8 after minimization of the influences of the most dangerous third order resonances by decreasing of lattice function beating in dispersion suppressor is equal 37 σ_x and 37 σ_y.

The design of the aluminum vacuum chamber in a bending magnet and synchrotron radiation absorbers allows to localize the gas loading at the high vacuum pumps disposal. The desorbtion stimulated by synchrotron radiation is the main source of gas loading in the vacuum chamber. Using the combined high productive sputter ion pumps and titanium sublimation ones provides the needed pressure in the vacuum chamber about $2\cdot 10^{-9}$ Torr. The pump limit pressure is better than $7\cdot 10^{-11}$ Torr and the pumping rate about 10^3 l/s. The installation of distributed NEG strips is also supposed to improve the vacuum.

Table 2

Energy at max. luminosity, GeV	2.2
Maximum energy, GeV	2.5
Luminosity, $cm^{-2}s^{-1}$	$1.1\cdot 10^{33}$
Number of interaction points	1
Beam lifetime, hours	3.5
Circumference, m	378
Momentum compaction	0.0351
Natural emittance, mm	482
Energy spread	$5.87\cdot 10^{-4}$
RF frequency, MHz	476
RF voltage, MV	18
Harmonic number	600
Bunch length, mm	7.5
Bunch spacing, m	12.6
Number of bunches	30
Total current, mA	614
SR energy loss, keV/turn	201
Synchr. radiation power, kW	123
Damping times $\tau_{x,y}/\tau_{\varepsilon}$, ms	27/14
Hor. beta at int. point, m	0.20
Vert. beta at int. point, m	0.01
Hor. beam size at IP, μ	303
Vert. beam size at IP, μ	15
Beam-beam parameter	0.035

The basic parameters of the tau-charm factory are given in Table 2.

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