PARTICLE DYNAMICS IN THE LOW ENERGY POSITRON TOROIDAL ACCUMULATOR: FIRST EXPERIMENTS AND RESULTS

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Abstract

The project of Low Energy Particle Toroidal Accumulator (LEPTA) is dedicated to construction of a positron storage ring with electron cooling of positrons circulating in the ring. Such a peculiarity of the LEPTA enables it automatically to be a generator of positronium (Ps) atoms, which appear in recombination of positrons with cooling electrons inside the cooling section of the ring. The project has a few goals: to study electron and positron dynamics in the ring (particle motion in the horizontal and vertical planes are coupled contrary to of classic cycle accelerators), to set up first experiments with Ps in flight; Magnetic measurements of main LEPTA elements are performed. Several elements: kicker, injection system of electron beam, helical quadrupole, septum magnet are tested and expected design parameters were achieved for those elements. The investigations of electron beam dynamics are started.

INTRODUCTION

The Low Energy Particle Toroidal Accumulator (LEPTA) is proposed for the electron cooling of positrons and generation of antihydrogen and positronium in flight [1÷4]. The LEPTA facility (Fig.1) includes small positron storage ring at circumference of 17.2 m equipped with electron cooling system and positron injector consisting of a low energy positron source based on β^+ -active sodium isotope and penning-type trap for preliminary storing of positrons. The energy of positron beam circulating inside the ring is planned to be 10 keV, the value of focusing magnetic field is equal to 400 G. Detector system for first experiments with positronium is under design.

The peculiarity of the LEPTA ring is the longitudinal focusing magnetic field for both circulating positron beam and cooling electron beam. The longitudinal magnetic field provides the positron magnetisation and, as a consequence, long lifetime of the circulating positrons. However, to form closed orbit of circulating beam one needs to use additional helical quadrupole coil. In the presence of longitudinal magnetic field the beam superposition and separation requires especial design of injection complex.

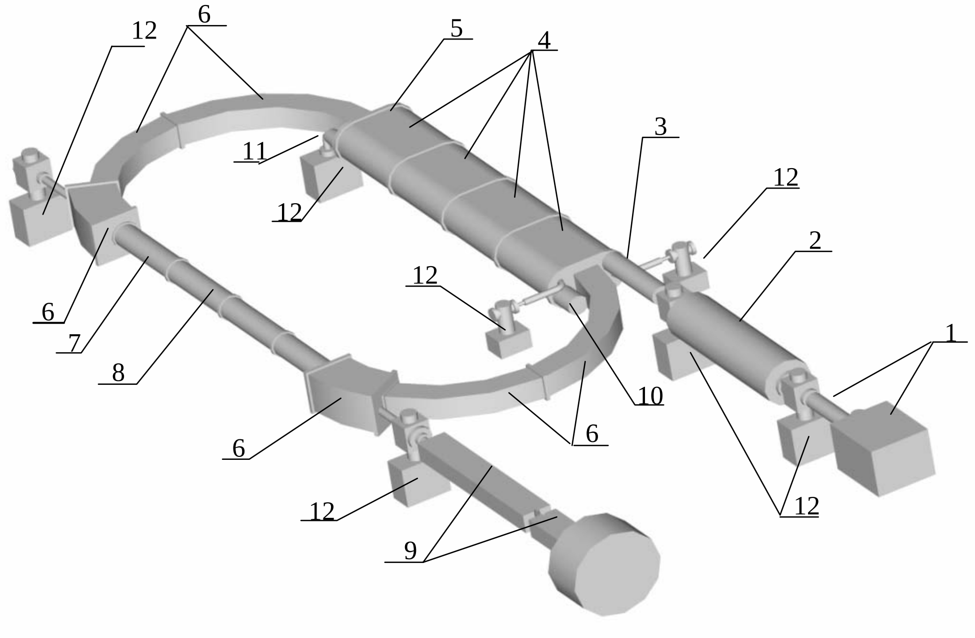

Fig. 1 Design of the LEPTA
1 – positron source, 2 – positron trap, 3 – positron transfer section, 4 – septum solenoids, 5 – kicker (inside septum solenoid), 6 – toroidal solenoids, 7 – solenoid and helical quadrupole inside it, 8 – electron cooling section, straight solenoid, 9 – experimental channel, 10 – electron gun, 11 – collector of the electrons, 12 – vacuum pumps.,

PARTICE DYNAMICS IN LEPTA RING

To form a closed orbit of circulating positron beam, the centrifugal drift of the positrons is compensated by applying a bending magnetic field in the toroidal sections of the ring. The long-term stability of the positron beam is provided by additional helical coil, which forms a quadrupole magnetic field, similar to the “stellarator” one. This coil consists of two pairs of spiral conductors with opposite current direction and is placed inside one of the straight solenoids around the vacuum chamber (Fig. 2). Required gradient of the quadrupole field was calculated using especially developed computer code BETATRON [5].

Helical quadrupole has to provide the beam rotation as a whole around its axis. The rotation angle is proportional to square of the quadrupole field gradient. The distortion of the angular spread of the beam after crossing the helical quadrupole is minimised by adiabatic variation of the quadrupole field gradient at the entrance and at the exit of the coil. The designed and constructed helical quadrupole coil has in each cross-section a geometry of "Panofsky lens" which provides a maximum linearity of the field (Fig.2). The gradient variation at the entrance and exit of the coil is provided by corresponding variation of the number of winding turns. A correct calculation of the particle dynamics in the coil is practically impossible due to difficulties in measurements of the fringe fields.

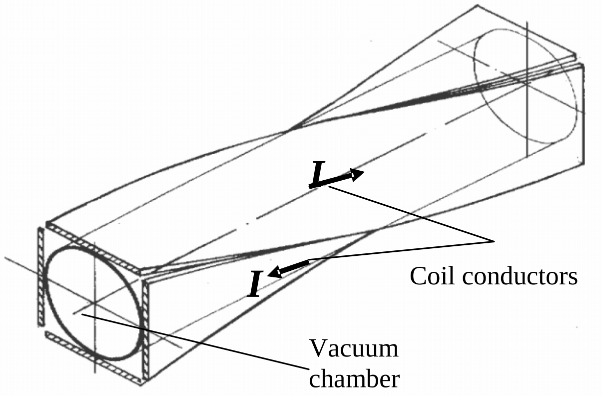

Fig.2. Scheme of the helical qudrupole.

Both beams – circulating positron and single pass electron one – are magnetised and the problems of the beams injection, superposition and separation are complicated enough in this case. These problems are solved by the following way.

At the first stage of the ring working cycle the electron gun is switched off. The positron beam from injector is directed into the septum coil and moves in horizontal direction to the equilibrium orbit. After that, it is displaced in vertical direction by the field of special electric kicker, which is placed in the septum solenoid next to the septum. At the exit of the kicker the positron beam has to reach the equilibrium orbit. Applying of bending magnetic field of the corresponding value compensates centrifugal drift of the positrons inside the toroidal sections. The field of the septum coils does not act on the particle moving along the equilibrium orbit owing to the septum design. When the positron beam fills the total ring circumference, the kicker is switched off and electron gun of the cooling system is switched on. The electron beam after travelling through the septum coil is placed below the median plane of the ring. Inside the first toroidal section electrons drift up in the longitudinal toroidal field and the bending one, which compensates the drift of the positrons. Total displacement of the electrons in vertical direction is equal to:

$$\Delta = \pi(\rho_p + \rho_e), \qquad (1)$$

where ρ_p, ρ_e are the positron and electron Larmor radii. Inside the cooling section both beams travel together (in the same direction), and both beams are overlapped. Inside the second toroidal section the electrons displace up again and to the left in the septum coil and come to the collector.

Tuning of the ring using test electron beam

General problems, which have to be experimentally investigated before to start experiments with positronium generation, are the following:
- beam parameter distortion during injection,
- beam parameter distortion after crossing the helical quadrupole,
- superposition and separation of two magnetised beams – circulating positron and single-pass electron ones,
- stability of the circulating beam,
- dependence of the circulating beam life time on vacuum conditions,
- variation of the circulating beam temperature due to transverse-longitudinal relaxation,
- beam parameter distortion after crossing the resonance of the fast mode of betatron oscillation.

Two special test benches were constracted for test of the septum and helical quadrupole. Other experiments will be done with circulating electron beam during the ring commissioning.

Test of the helical quadrupole was performed using two electron beams of diameter of 1.5 mm operated in the pulsed mode at pulse duration of 10 – 30 μs. Both beams were cut from a beam of diameter of about 13 mm at crossing a diaphragm with two small holes. Diameters of the holes are 1.5 mm and distance between the holes is 10 mm. One of the beams was aligned to the axis of the qudrupole using correction coils. Relative displacement of the second beam was measured as a function of the qudrupole winding current. Beam position at the exit of the system was observed with a luminescent screen. At the first stage of the experiment the dependence of beam rotation angle on the winding current was measured (fig.3). The dependence is in a good agreement with theoretical estimate for any value of the beam radial position. It is equal to:

$$\varphi = C\frac{G^2}{B^2}s \qquad (2)$$

where φ is beam rotation angle, *G* is magnetic field gradient which is proportional to the helical qudrupole current, *B* is longitudinal magnetic field, *s* is the qudrupole length, *C* is numerical coefficient which is defined by geometry of the qudrupole. Measurements of the angular distortion of the beam after crossing the quadrupole will be performed at the next stage of experiment using optic method of the beam temperature diagnostics.

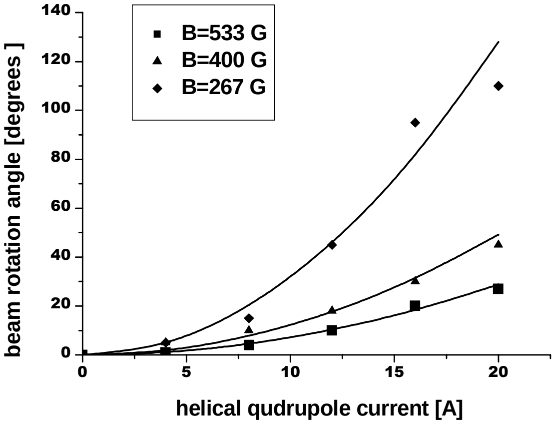

Fig.3. Dependence of the beam rotation angle on the helical qudrupole current for different longitudinal magnetic fields.

Tuning of the injection complex was performed at the second test bench. It included septum coils and kicker which were placed inside septum solenoid. Electron gun was installed at the exit of the kicker. Electron beam was moving in direction opposite to nominal one. Initially it was crossing the kicker then septum. At this test the kicker was used without electric plates. Inside vacuum chamber of the kicker the beam was shifed in vertical direction with correction coils. At the same current of the septum coil the beam was consecutively directed into three different channels of the septum: for injection of positrons, for circulating beam and for electron beam of the cooling system (fig.4).

At the exits of those channels the electron beam was observed with luminescent screens. Results of this test show good capability of the scheme for superposition and separation of magnetized beams.

After tuning, the injection complex was installed in the ring and the ring assembling was completed. The electron gun was installed at its nominal position (fig. 1). The electron beam orbit of the cooling system was traced. The pulsed electron beam generated by the electron gun passed through the septum and kicker, which operated without electric plates. In the toroidal solenoid the electron beam was shifted up to the equilibrium orbit by bending coil. In the straight section the beam position was measured using two pick-up stations.

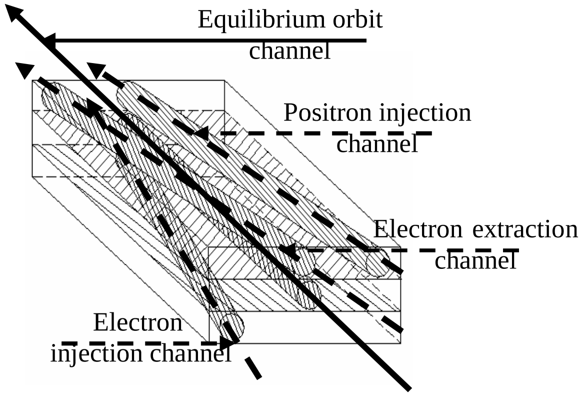

Fig.4. Septum scheme.

After the passage through the straight section the electron beam was shifted up again in the next toroidal solenoid. At the exit of the toroidal solenoid the beam entered the extraction channel of the septum and came to luminescent screen installed at the position of the electron collector. First turn of the beam in the LEPTA was done 13 April. At the next step we changed the polarity of the bending magnetic field in the second toroidal solenoid. As result the electron beam was not shifted, it had passed through the septum channel for circulating beam and had reached again the straight section at the second turn. The signals from pick-ups had increased by two times.

Now fabrication of the kicker elements is completed. The kicker is assembled and tested. After its installation into the ring the experiments with circulating electron beam will be started.

ACKNOWLEDGEMENTS

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