# THE LEPTA COMMISSIONING

E.Boltushkin, V.Bykovsky, A.Ivanov, A.Kobets, Y.Korotaev, V.Lohmatov, V.Malakhov, I.Meshkov, V.Pavlov, R.Pivin, I.Seleznev, A.Sidorin, A.Smirnov, E.Syresin, G.Trubnikov S.Yakovenko, JINR, Dubna, Russia

*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 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:

- Dynamics in the modified betatron
- Electron cooling with circulating beam
- Electron cooling of positrons
- Positronium generation in flight
- Positronium physics
- Feasibility of antihydrogen generation in flight

All key elements of the ring: kicker, electron beam injection system, helical quadrupole, septum magnet are tested and expected design parameters were achieved for those elements. LEPTA construction has been completed and circulating electron beam has been achieved.

This work is supported by RFBR grant #02-02-16911 and INTAS grant #03-54-5584.

## 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÷5]. The LEPTA facility (Fig.1) includes small positron storage ring with circumference of 17.2 m equipped with electron cooling system and positron injector consisting of a low energy positron source based on $\beta^+$ -active sodium isotope and penning-type trap for preliminary storing of positrons. The energy of positron beam circulating in the ring is planned to be at 10 keV, the value of focusing magnetic field is equal to 400 G.

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.

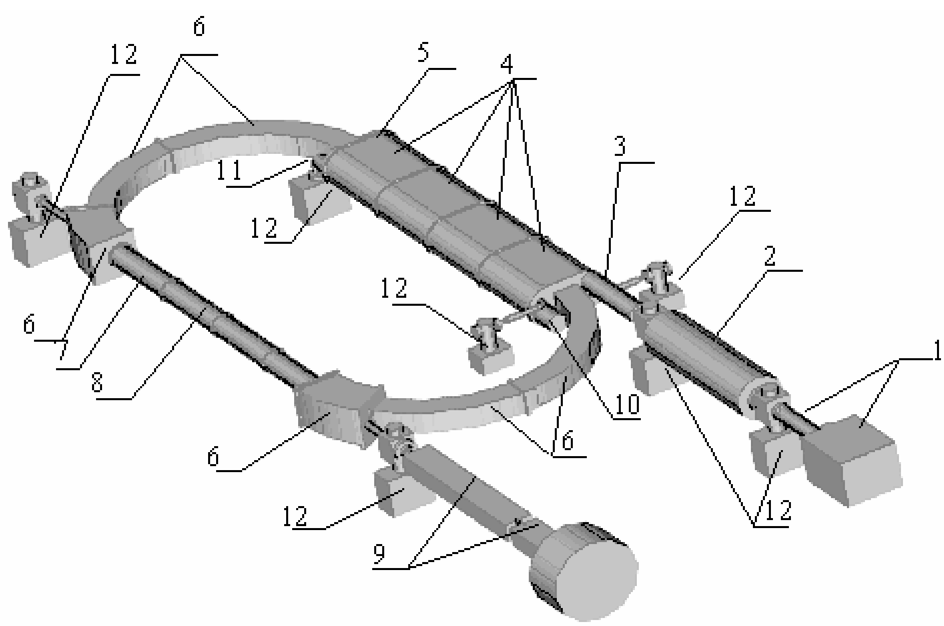


Figure 1: Design of the LEPTA. 1 – positron source, 2 – positron trap, 3 – positron transfer section, 4 – septum solenoids, 5 – kicker (inside septum solenoid), 6 – toroidal solenoids, 7 – solenoid and helical quadrupole inside it, 8 – electron cooling section, straight solenoid, 9 – experimental channel,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

## PARTICLE 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. Required gradient of the quadrupole field was calculated using especially developed computer code BETATRON [6].

Both beams – circulating positron and single-turn electron ones – are magnetized 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, which moves along the equilibrium orbit due 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 traveling 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 $\rho_p$, $\rho_e$ 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 drift up again and to the left in the septum coil and come to the collector.

General problems, which have to be experimentally investigated before starting 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 magnetized beams – circulating positron and single-pass electron ones,
- stability of the circulating beam,
- dependence of the circulating beam lifetime 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.

## TUNING OF THE RING KEY ELEMENTS USING PULSED ELECTRON BEAM

Tests of the injection complex and helical quadrupole were performed before the ring assembling. Other experiments will be done with circulating electron beam during the ring commissioning.

The 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 minimized 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 the 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.

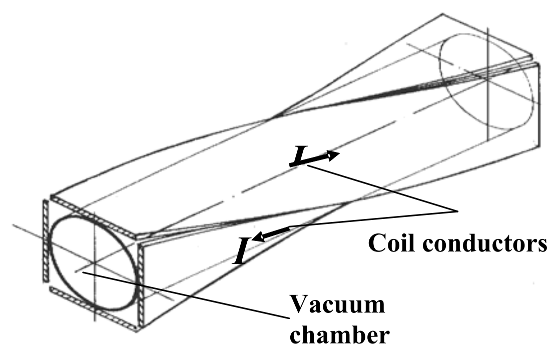


Figure 2: Scheme of the helical quadrupole

Test of the helical quadrupole was performed using two electron beams 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. Diameter of the holes was 1.5 mm and distance between the holes was 10 mm. One of the beams was aligned to the axis of the quadrupole using correction coils. Relative displacement of the second beam was measured as a function of the quadrupole 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 the beam rotation angle on the winding current was measured (fig.3). The dependence is in a good agreement with theoretical estimation for any value of the beam radial position. It is equal to:

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

where $\varphi$ is beam rotation angle, $G$ is magnetic field gradient, which is proportional to the helical quadrupole current, $B$ is longitudinal magnetic field, $s$ is the quadrupole length, $k$ is numerical coefficient defined by geometry of the quadrupole.

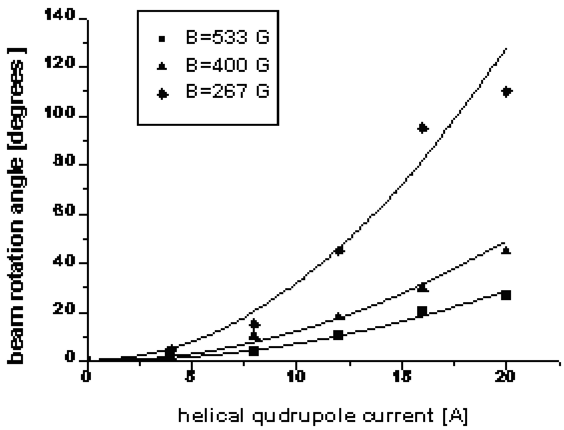


Figure 3: Dependence of the beam rotation angle on the helical quadrupole current at different longitudinal magnetic fields

The injection complex, which included septum coils and vacuum chamber of the kicker which were placed inside septum solenoid, was tested with electron beam from the electron gun installed at the exit of the kicker. Electron beam in this case was moving in the direction opposite to nominal one. First it was crossing the kicker, then the septum. At this test instead the kicker were used correction coils, which shifted the beam in vertical direction. At the same fixed current of the septum coil the beam was consequently directed into three different channels of the septum: positron injection channel, the tube for circulating beam and the tube for cooling electron beam (fig.4).

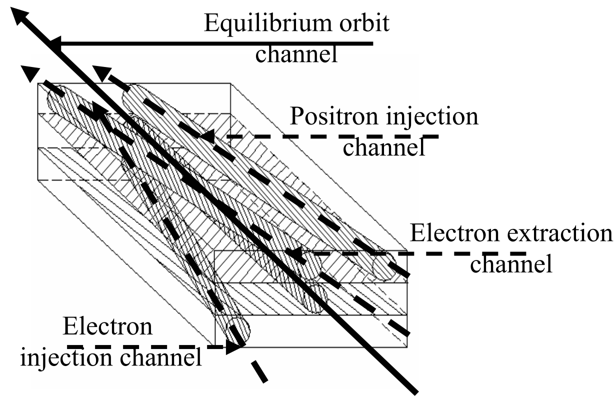


Figure 4: Septum scheme

At the exits of those channels the electron beam was observed with luminescent screens. Results of this test show a good capability of the scheme for superposition and separation of magnetized beams.
The injection complex was installed in the ring after the tuning 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.

## TUNING OF THE RING

When kicker was installed at the LEPTA the ring assembling was completed and tuning of the closed orbit was started. PU stations and segment diaphragms for diagnostics of the circulating beam were used (Fig. 5). Vertical and horizontal corrector coils placed before septum entrance allow the beam to pass the septum.

The optimal septum magnetic field was defined during the first test. Segment diaphragms placed at the kicker entrance allow more accurate septum tuning. Voltage of the kicker was optimized in accordance with necessary displacement (6 cm) of the beam up to the equilibrium orbit. This displacement was checked with segment diaphragms, which are placed at the exit of the kicker.

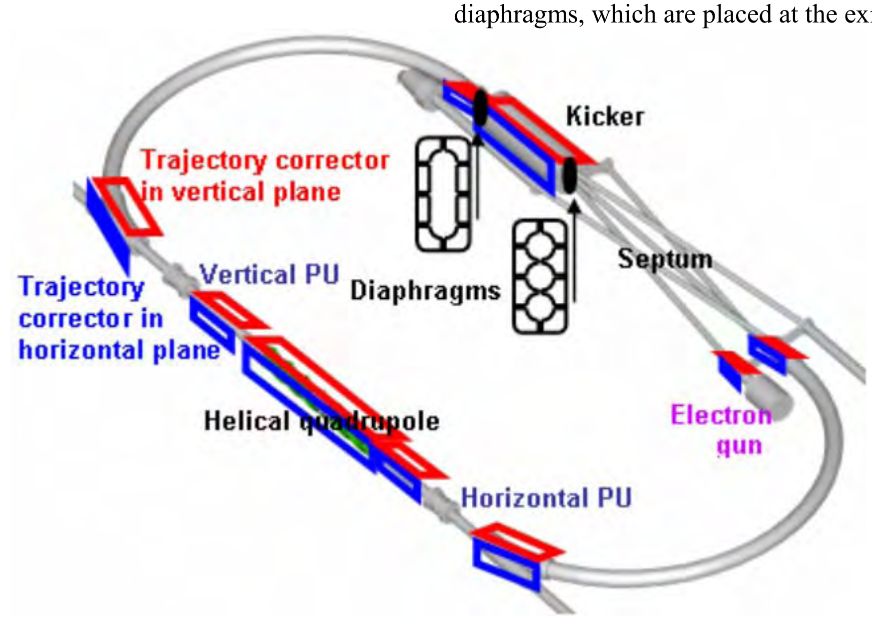


Figure 5: Beam diagnostic tools and correction coils disposition

Corrector coils, which are located at the entrance and at the exit of the first toroidal section, allow beam to pass the straight section. The beam was observed with two PU stations (Fig. 6), which are installed in the straight section. Each station consists of two plates formed from a cylinder cut along axis.

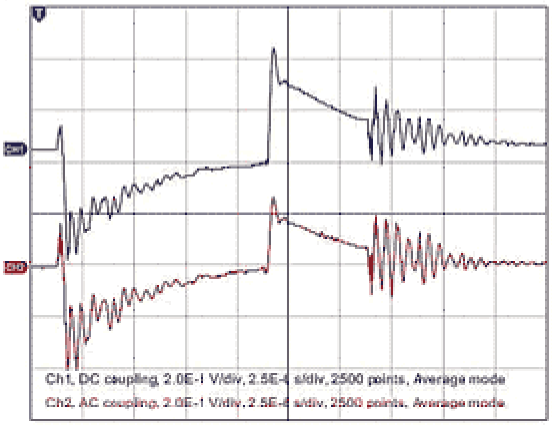


Figure 6: Signals from vertical PU station. Time scale: 2,5 μs/div. Top curve is signal from top plate of the PU station and bottom curve – from bottom plate

Duration of the signal from PU was about 10 μs (Fig. 6), but length of injected beam was about 15 μs (Fig. 7).

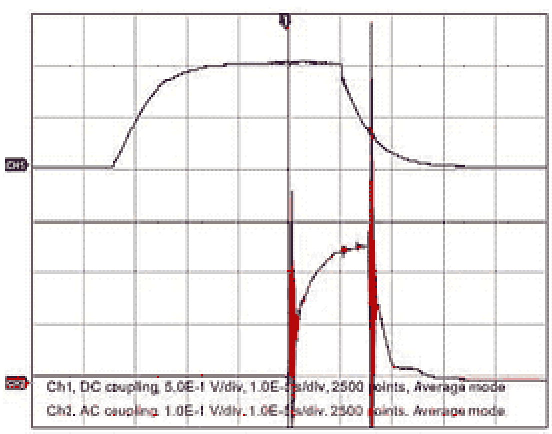


Figure 7: Time dependence of kicker signal (top curve) and pulse of injected electron beam (bottom curve). Time scale: 10 μs/div

The kicker has been turned on before injection of the electron beam, and has been turned off when electron beam fills the whole equilibrium orbit. Electron beam was observed with PU at the moment only when the kicker is switched on. On the next step beam was passed through the second toroidal section using corrector coils at the entrance and exit of second toroidal section. Position of electron beam was controlled with segment diaphragm placed at the exit of central channel of the septum.
Circulating electron beam was observed also with PU after back edge of the kicker pulse (fig.8). Only a few

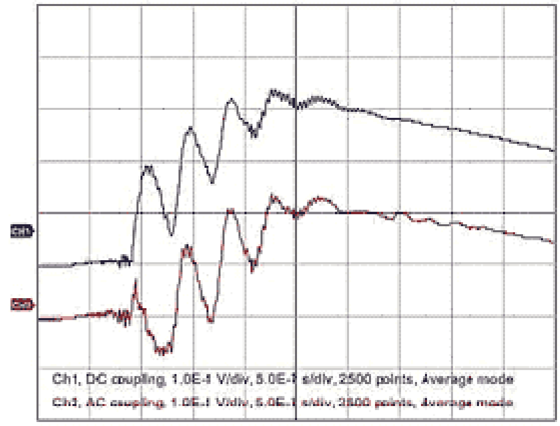


Figure 8: A few first turns of the beam in the ring. Signals from vertical PU station

turns exist without the helical quadrupole filed. The helical quadrupole allows achieving the stable motion in the ring. The back edge of the kicker pulse is about 30 ns, the revolution time is about 300 ns. As result when kicker is turned off the circulating beam does not fill the whole equilibrium orbit and circulating beam can be observed with PU (fig.9).

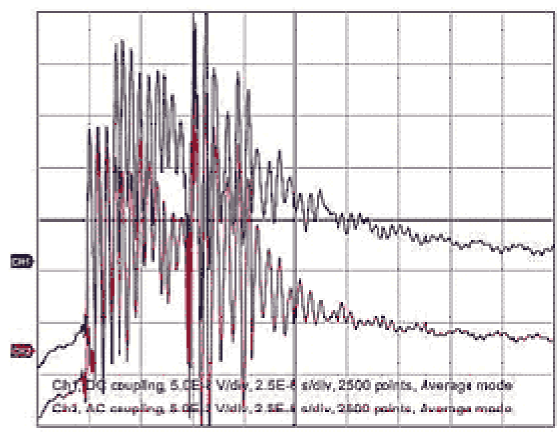


Figure 9: Circulating beam. Signals from vertical PU station

Some noise exists at the moment when electron gun turns off. To avoid this problem the signal from circulating beam was transformed to computer (fig.10, black curve). Then the closed orbit was broken using corrector coil, which is placed at the end of the straight section, i.e. the electron beam makes one turn only, and PU signal from injected beam was not changed. The signal from the injected electron beam was transformed to computer also (fig.10, top (red) curve). On the next step the signal from circulating beam (fig.9) was subtracted by the signal from injected beam (fig.6). As result the clear useful signal of the circulating beam was obtained (fig.10, bottom (green) curve).

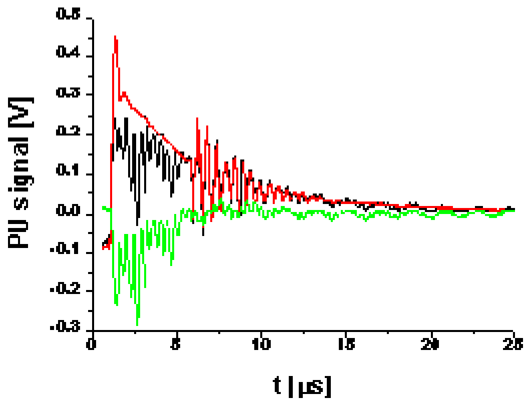


Figure 10: The digital signals from vertical PU

In accordance to the calibration of PU stations the circulating beam current in the first turn was about 60 mA. The injected beam current was about 120 mA. Circulating beam is observed during 10 μs that corresponds to 20 turns. Then the amplitude of the PU signal continuously decreases. It means the beam becomes coasting or disappears. However the small amplitude of PU signal with slow frequency during 200 μs was observed (fig.11). Sometimes this signal was modulated with the revolution frequency. The slow frequency corresponds to a rotation of the beam as a whole around the axis and is produced by the field of the helical quadrupole.

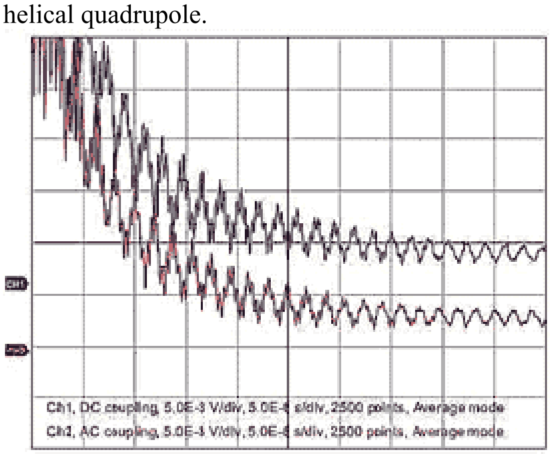


Figure 11: Slow mode of oscillation. Signals from vertical PU station

The measurement this slow betatron tune dependence on the helical quadrupole current was done (fig.12). The slow betatron tune is equal to

$$Q = \frac{f_{slow}}{f_{revolution}} \qquad (3)$$

The signals of slow frequency from different plates of PU station have the opposite phase (fig.11) that confirms the rotation of the beam as a whole. Approximation of the experimental dependence of the rotation angle on the quadrupole current with parabolic curve shows that the ring has additional focusing by nonlinear magnetic field of the bending coils in toroidal section or the space charge of the electron beam influences on beam dynamics. Both effects or one of them make the beam rotation in the direction opposite to the helical quadrupole one.

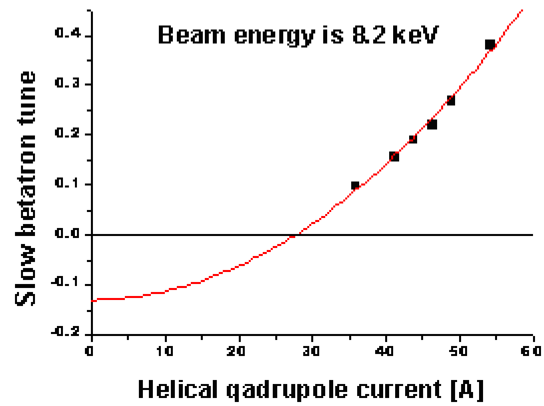


Figure 12. The dependence of the slow betatron tune on the helical quadrupole current

## SUMMARY

New storage ring LEPTA was assembled at JINR. First experiments with the pulsed electron beam show the validity of the injection scheme. The circulation of the electron beam was observed for a few hundreds turns.

## REFERENCES


[1] I.N. Meshkov, A.N. Skrinsky, Antihydrogen beam generation using storage ring, NIM A 379 (1996) 41, preprint JINR E9-95-130, Dubna, 1995.

[2] I.N.Meshkov, A.O.Sidorin, Conceptual design of the low energy positron storage ring, NIM A 391 (1997), 216 – 220.

[3] Yu.V.Korotaev, I.N.Meshkov, S.V.Mironov, A.O.Sidorin, E. Syresin, The low energy positron storage ring for positronium generation, Proc. of EPAC 1998, p. 853

[4] I.Meshkov, A.Sidorin, A.Smirnov, E.Syresin The particle dynamics in the low energy storage rings with longitudinal magnetic field, Proc. of EPAC 1998, p. 1067.

[5] V.Antropov, E.Boltushkin, V.Bykovsky, et al. Particle dynamics in the Low Energy Positron Toroidal Accumulator, first experiments and results, Proc. of EPAC 2004.

[6] I.Meshkov, A.Sidorin, A.Smirnov, E.Syresin, G.Trubnikov, The computer simulation of the particle dynamics in the storage ring with strong coupling of transverses modes, Proc. of EPAC 2000.