METHODS FOR OPTIMIZATION OF THE DYNAMICS OF THE STORAGE OF POSITRONS IN THE SURKO TRAP*

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Abstract

Surko traps are used successfully, example, for the accumulation of positrons and antiprotons in the experiments on the generation of antihydrogen atoms the ALPHA/CERN. The report presents methods for optimizing the dynamics of the storage of positrons in the Surko trap based on experimental studies on the trap the facility LEPTA/JINR and theoretical estimates of the accumulation and dynamics of particles with technique "Rotating Wall".

INTRODUCTION

Open Penning-Malmberg trap successfully used in the generation of antihydrogen experiments ALPHA [1]. For the accumulation and compression of charged plasma of positrons and antiprotons before injection into the central part of the trap with magnetic mirrors, restraint produced atoms of antimatter, the method of rotating electric field (RW-«rotating wall") [2]. Stabilizing and compressive action of RW-field was first discovered in experiments on the accumulation of ions Mg+ [3]. Then the method used in the experiments with electron [4] and positron bunches [5]. In our experiments on the LEPTA [6,7], whose ultimate goal is to generate a directed flow of atoms of orthopositronium, we investigated the accumulation of positrons before introducing them into the storage ring. It was found that an increase in the lifetime and the number of accumulated particles of the bunch requires highly monochromatic flux of positrons from the sources. A study of instabilities of a non-neutral plasma in the trap, limiting the lifetime and the number of particles accumulated a bunch of positrons [8].

EXPERIMENTS

We represent the results of our experiments on the accumulation of electron and positron plasma in the trap Surko.

Experiments setup

Our facility is the trap open Penning-Malmberg type in the form of the hollow cylinder. Confinement of non-neutral plasma in the transverse direction with respect to the axis of the trap is carried out by the longitudinal of magnetic field magnetic field produced by solenoids. In the longitudinal direction of the storage plasma electrostatic potential for blocking electrodes. One-third of the storage region by the accumulation of the split RW-electrodes, giving the opportunity to include in the accumulation of rotating in the transverse direction the RW electric field.

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Typical values for our the trap are shown in Table 1:

Table 1: The typical parameters of the our the trap

Parameters	Value	Comments
E_ω, V/cm	0.05	RW electric field
f_{RW}, kHz	600	Frequency RW-field
n_e, cm^{-3}	$10^7 \div 10^8$	Density of storage particle
ω_p, c^{-1}	$3.5 \cdot 10^7 \div 2 \cdot 10^8$	Plasma frequency
B, Gauss	1200	Longitudinal of magnetic field
ω_B, c^{-1}	$2 \cdot 10^{10}$	Cyclotron frequency
p_{N2}, Torr	$2 \cdot 10^{-6}$	Buffer gas pressure (in storage region)
R_T, cm	10	Radius of transverse plan electrode in the trap (in storage region)
L_T, cm	48	Length of the electrodes in the trap (in storage region)
R, cm	$\sim 1 \div 2$	Radius of transverse plan the storage bunch
L, cm	~ 40	Length of the storage bunch

Inside the trap creates a vacuum base. To capture the particles in the trap from a buffer gas (nitrogen) is used. The role of the buffer gas will be discussed further on. To trap a series of experiments were conducted with both electrons and positrons with. Here we can distinguish experiments:

- by measuring the collector current for damp the bunch collector,
- on photographing the dump discharge in the bunch to bunch phosphor screen,
- to measure the signal from the photomultiplier tube at the positron annihilation bunch.

Storage of the electrons. Results of experiments with the collector

Measurements of the collector current can determine the number of storage particles. Performing these measurements at fixed times, we define the dependence of the accumulated particles from the accumulation time. To clarify the role of the rotating field, we carried out experiments on and off the field during accumulation. The results are shown in Fig. 1. Accumulation occurred at found us the optimal parameters: buffer gas pressure, the

magnitude magnetic field, amplitude, frequency and the direction of rotation of the RW-field.

Obviously, the strong influence of the rotating field in the process of storage. Proper use of this field allows you several times to increase the number of storage particles.

Results of experiments with the CCD camera. Compress the bunch rotating field

Next, we directly measured changes in the transverse dimensions of the bunch during the accumulation of the CCD camera, courtesy of colleagues of Budker INP.

The experiments presented in Figure 2. carried out as follows. Century 30 seconds went accumulation of electrons in the trap. Then turned off injection of particles into the trap and deduct the confinement particles. Switched on while holding the rotating field. From the experimental data shows that with increasing time of this field is compressed in the transverse bunch sizes. On brightness can be concluded that in the centre of the bunch increased concentration of particles. When you turn off the rotating field is the reverse process, i.e. expansion of the bunch.
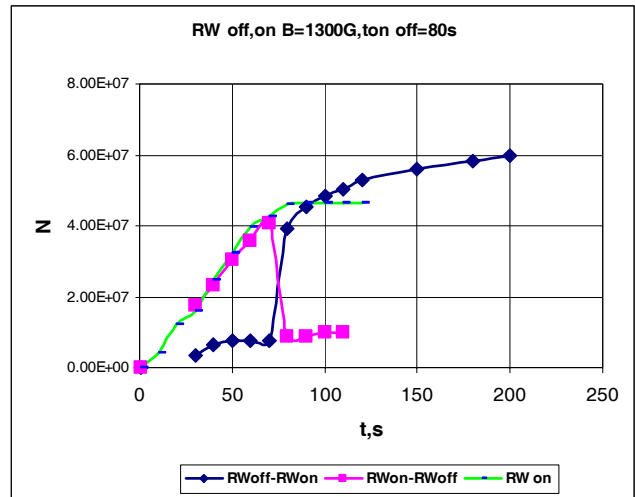

Figure 1: The dynamic storage electron bunch. Curve RWoff-on is dependence of the number of stotage particles from the accumulation time, the RW-field is on after 80 sec. Curve RWon-off – the RW-field is off after 80 sec. Curve RWon – the RW-field is on all time of storage.
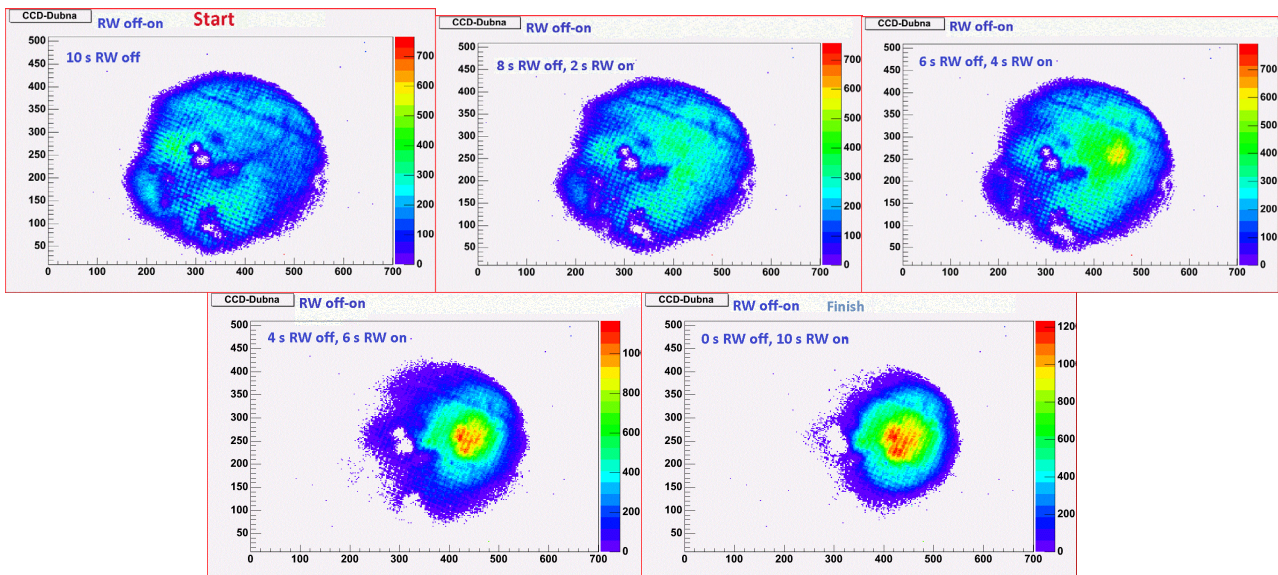

Figure 2: The photo (CCD) transverse plane of the storage electron bunch independent on time RW-field work. The effect is the bunch transverse compression RW-field.

First experiments with positron storage

The experiments on slow positron accumulation into the positron trap were stared. The first results of the experiments are presented in the Figure 3. The experimental curve of the trapped positrons versus accumulation time (Upt – the signal from photoelectron tube proportional to the number of the accumulated positrons).These experiments show that the rotating field increases the number of accumulated particles, the lifetime of the bunch and compresses the bunch in the transverse size.
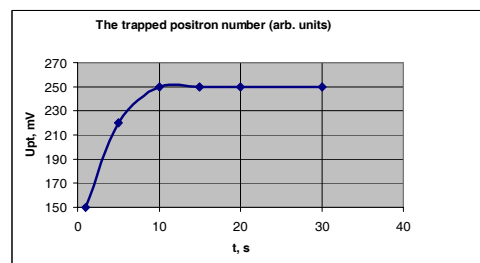

Figure 3: PMT signal (proportional to the trapped positrons number) vs accumulation time.

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TIMING OF THE TRANSVERSE AND LONGITUDINAL MOTION OF THE BUNCH IN THE TRAP

In the theoretical analysis of the accumulation of particular interest to the role of the rotating field. It should be noted that the frequency of the rotating field is significantly different from the characteristic frequencies for a fiery bunch in a magnetic field (see Table 1.). Previously, it was determined that the frequency and direction of this RW-field should coincide with the drift of the particle bunch in the crossed fields of space charge and longitudinal magnetic field [9]:

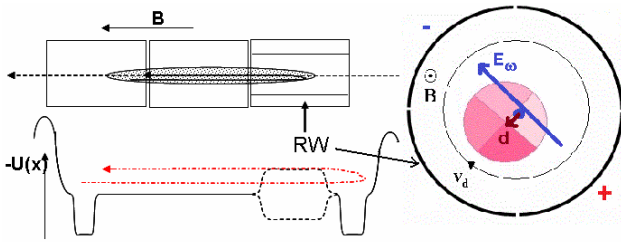$$ f_{RW} \gg f_E = \frac{cE_R}{2prB} = \frac{cne}{B} . \tag{1} $$

Figure 4: Simulation of transverse and longitudinal motion of the bunch in the trap.

In the accumulation of a small number of positrons [10] has been observed that this frequency is in good agreement with the frequency of the bounce motion of particles trapped. Also stated that the storage region occupied by the RW-electrodes should not take more than half of the region storage of particles.

On the basis of solving the equations of motion of particles and simulation confinement the bunch in the trap, we can offer the following explanation of the influence of the RW-field (see Fig. 4.). Continuing the particles at entry into the trap of quickly thermalized (to the velocity of thermal motion υ_{term}) by collisions with buffer gas molecules. The frequency (or period) of longitudinal oscillations (or period) of the particles on the order of frequency drift motion (1):

$$ T_{long} \approx 2L/\upsilon_{term} \approx T_E \approx 1-3 \ \mu s \ , \ f_{RW} \approx T_{long}^{-1} \approx f_E . $$

This synchronization (auto synchronization) and provides a grouping of particles and subsequent compression of the bunch. Rotating field shifts the center of the bunch with respect to the trap axis, creating a non-zero dipole moment **d**. And while confinement the bunch particles must from time to time to leave the area of a rotating field, in order to whip in those moments when the field has a maximum torque of forces in the bunch:

$$ M_\theta^{RW} = \frac{dP_\theta}{dt} = \mathbf{d} \times \mathbf{E}_\omega . $$

Until the particles come out of a bunch of RW-electrodes in the RW-field of the electrodes should rotating so as to provide maximum torque the bunch about the trap axis.

Because of the magnetic field inhomogeneity and scattering on residual gas bunch slows its rotation. This leads to an increase in the drift of particles to the walls of the trap. Synchronization of the longitudinal and transverse motion of particles trapped in the RW-field provides the greatest "spinning" the bunch, and compensates for the slowing rotation. This increases the stability and lifetime of the bunch. However, the mechanism of compression of the bunch due to the RW-field remains uncertain.

METHODS OF POSITRON LIFETIME INCREASE AND BUNCH COMPRESSION. THE MAIN RESULTS

1. Optimal parameters of the Surko trap at LEPTA have been found:
- magnetic field value B>1000 G,
- base vacuum ~ 10^{-9} Torr,
- buffer gas pressure in storage region ~ 10-6 Torr,
- RW amplitude = 0.5 V and frequency ~ 600 kHz,
- RW rotation direction along the particle drift;

2. Compression and stabilization of the stored bunch by RW-field application:
- achievable bunch life time > 100 sec,
- achievable stored particle number > 10^9 (electrons), 10^7 (positrons),
- achievable bunch transverse size < 1 cm;

3. Bunch intensity increase by the controlled storage regime:
- dynamic magnification of frequency of the RW field and depth of the potential well with growth of number of the storage up particles.

RESULTS AND DISCUSSION

- "The Rotating Wall" method was studied experimentally at LEPTA injector and a high efficiency of particle storage with RW application has been obtained.
- Optimal Surko trap parameters have been found.
- It was found that the RW mechanisms were discussed at the LEPTA Trap parameters.
- Methods of optimization of the particle storage and bunch compression in the Surko trap has been obtained.
- First experimental results of positron storage in the LEPTA trap have been presented.

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