COMPRESSION AND CONFINEMENT OF POSITRON CLOUDS IN THE SURKO TRAP OF LEPTA FACILITY*

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Abstract

A bunch of positrons confined in a cylindrical Penning-Malmberg trap can be compressed radially by applying a rotating asymmetric dipolar electric field. An explanation of this effect presented in the report is based on the solutions of particle 3D dynamics equations in the fields of the trap taking into account the positron collisions with a neutral buffer gas. The result agrees well with experimental data obtained at the positron injector of LEPTA facility at JINR. Essential feature of the compression process is resonant character of applied rotating field and coincidence its frequency with the frequency of longitudinal positron bouncing in the trap.

INTRODUCTION

The LEPTA facility consists of the source of positrons, the trap and storage ring for generating positronium stream [1]. The Penning-Malmberg trap operates in pulsed mode, accumulating positrons from the source. At accumulation is important to increase the number of the storage particles and clouds in the lifetime of the trap and optimized parameters for this accumulation. It is important to ensure the uniformity of the longitudinal, in relation to the axis of the trap, the magnetic field required pressure of the buffer gas (nitrogen), the distribution of confining potential (see Fig. 1).

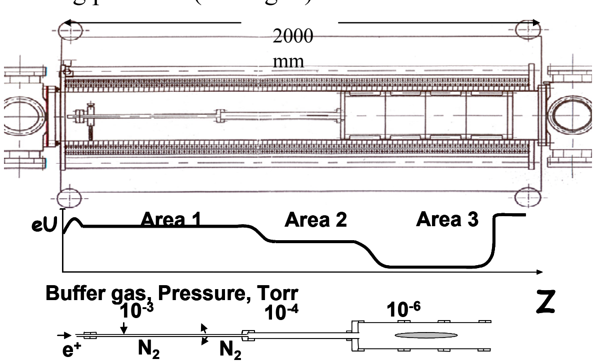

Figure 1: The scheme of the trap. Longitudinal section. Injector accumulated particles to the left in Figure.

In the Surko trap the rotating electric field (the RW-field) created by the electrodes of discontinuous (see Fig. 2). This can significantly improve the accumulation of particles [2,3]. The trap scheme is shown in Figure 1. Previously presented the optimal parameters of accumulation of particles in the trap [4]. Mechanism of action of the rotating field on the accumulation of particles has been discussed. There are different approaches to explain this effect [3,5,6]. For further consideration is the formulation of hypotheses about the need to consider context of longitudinal and transverse motion of the particles in the trap to explain the effect of the rotating field. Will also present experimental verification of the hypothesis.

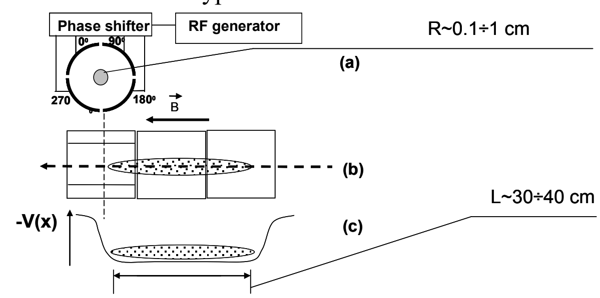

Figure 2: "Rotating wall" (RW) technique: rotating electric field at the trap entrance.

3D-DYNAMICS OF PARTICLE

What is the mechanism for increasing the lifetime confinement and focus particle clouds the use of RW field?

3D-hypothesis

Consider the field and the forces acting in the transverse and longitudinal section of the trap on the particle (see Fig. 3). This is **B** – the longitudinal magnetic field (axis z), $\mathbf{E}_R$ – the field of the space charge of the particle cloud, $\mathbf{E}_\omega$ – the rotating wall field, $\mathbf{E}_{b,r}$, $\mathbf{E}_{b,z}$ – transverse and longitudinal component of the field locking electrode traps.

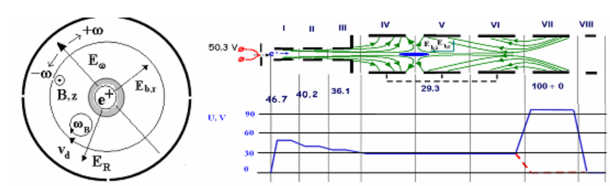

Figure 3: Field distribution in the trap in the longitudinal and transverse section.

Previously, we and other authors have noted the good agreement of the resonance frequency of the RW field f with the drift frequency in the transverse direction $f_{drift} = cE/B$. Some studies indicated agreement with the longitudinal bounce frequency f. This allowed us to assume that the effect of compression and increase the lifetime of clouds stored particles is observed in agreement longitudinal and transverse 3D-motion of the

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particles. Phase entry of the particle in the rotating field is defined as a transverse drift, and longitudinal motion. As shown below, the particles trapped in the correct phase RW-field has a focusing effect, offsetting the particle scattering by inhomogeneities of the magnetic field traps.

The Equations of Motion of the Particles and the RW Field Effect

Rotating field work effectively only with the concurrence of the longitudinal and transverse movements. The action of the buffer gas (nitrogen) can be approximated to shine viscous friction $F_{fr} = -k \cdot V$, where k – friction coefficient, V – particle velocity. As the result, the equations of motion can be written as:

$$m\ddot{\mathbf{r}} = e\left(\mathbf{E}_R + \mathbf{E}_b + \mathbf{E}_\omega\right) + \frac{e}{c}\left[\mathbf{V}\times\mathbf{B}\right] - k\mathbf{V},$$

where e, m - the charge and mass of the particles. In the projections, we have

$$\begin{cases} \ddot{x} = \dfrac{\omega_p^2}{2}\left(x - x_c\right) + \dfrac{\omega_z^2}{2}x + \dot{y}\omega_c - A_\omega\left(z - Z_0\right)\cos[\omega\cdot t] - K\dot{x} \\ \ddot{y} = \dfrac{\omega_p^2}{2}\left(y - y_c\right) + \dfrac{\omega_z^2}{2}y - \dot{x}\omega_c + A_\omega\left(z - Z_0\right)\sin[\omega\cdot t] - K\dot{y} \\ \ddot{z} = -\omega_z^2 z - K\dot{z} \end{cases}$$

Where $K = k/m$, $A_\omega = eU_\omega/\left(2mR_0Z_0\right)$, $U\left(z,r\right) = U_0\left(z^2 - r^2/2\right)/\left(2d^2\right)$, $\omega_z = \sqrt{eU_0/md^2}$ - bounce frequency, $\omega_p = \sqrt{4\pi ne^2/m}$ - plasma frequency, $\omega_C = eB/\left(mc\right)$ - cyclotron frequency, U_0 – well depth of accumulation, $d^2 = \left(Z_0^2 - R_0^2/2\right)/2$.

The longitudinal motion - oscillations:

$$z \approx z_0\cos[\omega_z t + \varphi_0].$$

Transverse motion in a strong magnetic field - fast cyclotron rotation with frequency $\omega_+ \approx \omega_c$ and the slow rotation of the magnetron frequency $\omega_- \approx \left(\omega_p^2 + \omega_z^2\right)/2\omega_c$. Movement goes in the projections:

$$x_+ = r_+\sin[\omega_+ t + \Phi],\ y_+ = r_+\cos[\omega_+ t + \Phi],$$
$$x_- = r_-\sin[\omega_- t + \Phi],\ y_- = r_-\cos[\omega_- t + \Phi].$$

Transmits power RW-field of the moving charge $P\left(t\right) = e\mathbf{E}_\omega\left(\dot{\mathbf{r}}_+ + \dot{\mathbf{r}}_-\right)$:

$$P\left(t\right) = mA_\omega(r_+\omega_+\sin\left[\left\{\omega - \omega_+\right\}t + \Phi\right] +$$
$$+ r_-\omega_-\sin\left[\left\{\omega - \omega_-\right\}t + \Phi\right])$$

(Φ - phase entry of the particle in the RW-field). If $\omega = \omega_- = 2\pi f_{drift}$, then $\overline{P}_- = mA_\omega r_-\omega_-\sin\left[\Phi\right]$, and $r_-\left(t\right) = r_-\left(0\right) - A_\omega t\left(\omega_+ - \omega_-\right)$ for $\Phi = \pi/2$. We see focusing to the axis of the trap effect of the RW-field.

EXPERIMENTAL VERIFICATION OF THE 3D-HYPOTHESIS

We checked (June 2012) the dependence of the resonance frequency of the rotating field of the bounce frequency $f_Z = \omega_Z/2\pi \approx \upsilon_{\parallel}/2L$ ($\upsilon_{\parallel}$ - the longitudinal velocity), changing the length of the accumulation. The length of the accumulation is manipulated by controlling the confining potential at the electrodes V-VIII (see Fig. 3). In this case, we have changed the frequency of the rotating field and observed it will change in the number of accumulated particles at different points in time (see Fig. 4). This dependence shows that the maximum number of stored particles for each length of accumulation is reached at the specific frequency RW-field. This resonance frequency increases with decreasing length of storage. We also determined the dependence of the lifetime of the cloud of particles accumulated on the RW-field frequency for different lengths of accumulation. (see Fig. 5). Analysis of the dependences shows modifies the lifetime and resonant frequency of the RW-field at different lengths of storage. Possible to observe several peaks lifetime at multiple frequencies (see Fig. 5 a). Another interesting result: the accumulation does not occur if the area of accumulation is only within the RW-field. That is, the particles must be in the rotating field is not all the time, and select the phase of entry into this field. This supports the hypothesis about the relationship of the longitudinal and transverse motion of the particles in the trap with the frequency of the rotating field. For greater clarity, the longitudinal evaluation of the bounce frequency of and agreement to the resonant frequency of the rotating field for various lengths of storage were presented in the Table 1.

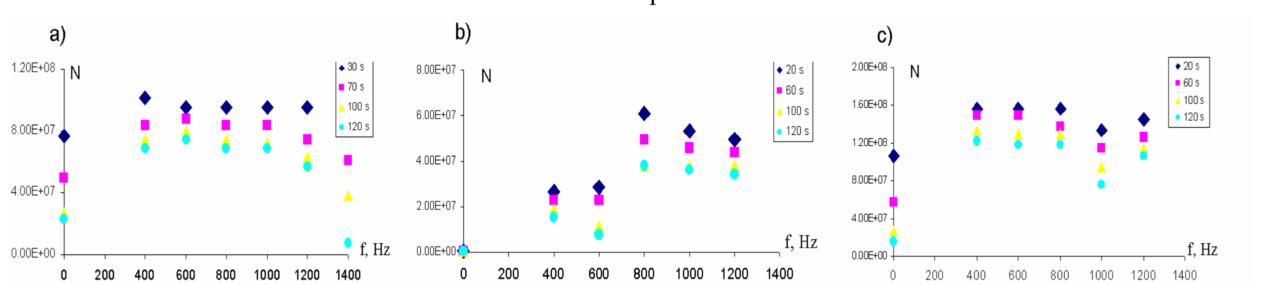

Figure 4: The dependence of the number of particles accumulated on the frequency of the rotating field for different lengths of accumulation: a) L=72 cm, b) L=48 cm, c) L=32 cm.

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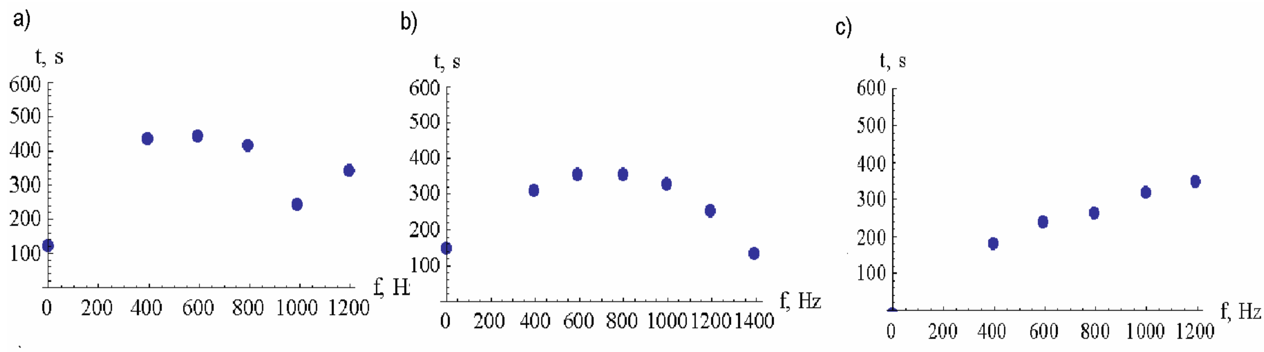

Figure 5: The dependence of the lifetime of a cloud of particles accumulated on the frequency of the rotating field for different lengths of accumulation: a) L=72 cm, b) L=48 cm, c) L=32 cm.

Table 1: Relationship with the length of the accumulation of frequencies.

Length of accumulation, L, cm	**Bounce frequency,** f_Z, kHz	**Resonance RW frequency,** f, kHz
72	600	600
48	850	800
32	1200	>1100

SUMMARY AND OUTLOOK

- The optimal parameters, which significantly increase the lifetime of the cloud and compress the accumulated particles.
- Proposal the 3D-hypothesis on the relationship RW frequency field, the frequency of the longitudinal motion and frequency drift motion.
- Resolved the 3-dimensional equations of motion of particles in the trap and show the focusing effect of the rotating electric field. Particles for the RW-mechanism work should not always be in the RW field, and at the right time, "dive" under its action necessary phase.
- Communication of the resonance frequency RW field and the bounce frequency of the longitudinal motion has been confirmed experimentally.

Further development of methods compression and storage of the positron clouds in the trap will improve the injection positron [7,8] in the storage ring LEPTA facility.

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