Progress in VECC Penning Trap Development

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Introduction

A cryogenic Penning trap facility is under development at Variable Energy Cyclotron Centre, Kolkata. In this report, we describe initial results in running the trap with electrons generated from a field emission source at liquid nitrogen temperature using a low magnetic field (~400 Gauss). In a Penning Trap, a charged particle could be trapped three dimensionally by the application of a homogeneous axial magnetic field and weak quadrupolar electrostatic potential. The charged particle undergoes a complicated motion comprising axial, cyclotron and magnetron motion. The axial frequency depends on the applied electrostatic potential and mass of the charged particle. In the case of the electrons, the axial frequency is about 60 MHz (for trap voltage ~10V) and we attempt to detect the axial oscillation of a cloud of electrons by swept tuned resonance technique. The oscillating electrons induce image current in the end-cap electrodes. The image current is sent through a LCR tank circuit. As the axial oscillation frequency of the trapped electrons is varied by varying the electrostatic potential, resonance occur when the oscillation frequency matches with the fundamental frequency of the LCR tank circuit. Thus, the trapped electrons absorb energy from the tank circuit and consequently a resonant damping in the response of the circuit would be observed. The signal from tank circuit is mixed with resonance frequency signal and passed through a low pass filter. Finally, the beat signal is seen as a dip above the noise level.

Penning trap arrangement

We have used a 5-electrode cylindrical Penning trap arrangement. The details of our arrangement had been described in ref [1]. A reasonable quadrupolar electrostatic potential over ~2 mm in a total length of trap of 26.08mm is created by the 5 cylindrical electrode arrangement. A high vacuum on the order of 10^{-9} mbar has been achieved by using a turbo-molecular pump along with an ion pump and cooling the system to liquid nitrogen temperature. Since our liquid helium cooled superconducting magnet was not available, a low field magnet was fabricated using small permanent bar magnets. We have used an annular iron bar of diameter 70 mm (i.e. same as the diameter of vacuum chamber), thickness 30 mm and height 60mm. We have placed 12 bar magnets on the top and the bottom of the iron bar to closely fabricate a homogenous annular magnet. To check the homogeneity of the magnetic field, the magnetic field was measured using a hall probe in axial and radial direction and tesla meter (F.W. Bell; model:7330). Fig. 1 shows the variation of magnetic field in the axial direction.

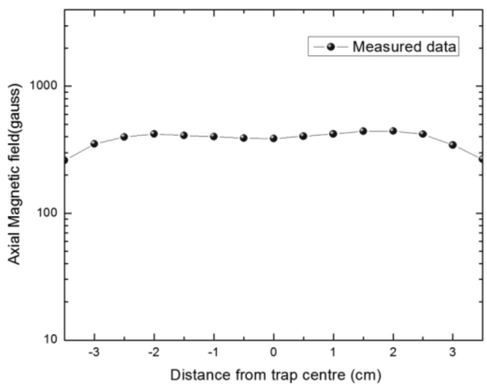

Fig. 1: Variation of axial magnetic field with distance from the trap centre

Fig. 2 shows the electronic circuit of our trap for the detection of the trapped electrons. The upper end-cap of our trap is A.C. as well as D.C. grounded. Both the compensation electrodes and the ring electrodes are connected together with a 1MΩ resistance to the signal generator which provides the ramp voltage. One line from the lower end-cap of the trap is connected with the upper end cap with 1MΩ resistance which assures same D.C voltage as upper endcap but keep the electrode A.C. floated which allows signal pickup. Another line from the lower end cap is connected to the tank circuit that is further connected to the amplifier. As the lower end cap of our trap is connected to an inductance L , it forms a tank circuit together with the trap electrodes and connecting wire acting as a capacitance. The third line from the lower end cap is connected to a different signal generator which weakly excites the tank circuit at its resonance frequency.

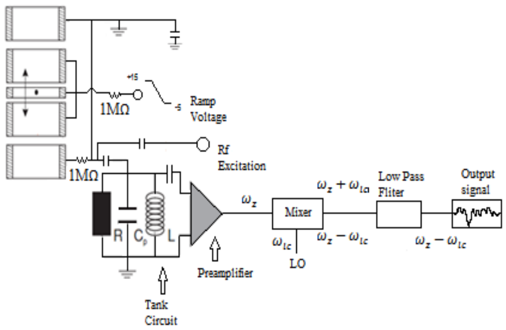

Fig. 2: Electronic Circuit diagram

Observations from the initial runs

It is necessary to send relatively low energy electrons (~200 eV) through the trap system and they would produce thermal energy secondary electrons by colliding with the residual gas. The electrons of ~200 eV energy have the highest cross-section for producing secondary thermal energy electrons [2]. However, field emission from the tungsten tip occurs at a few kilo voltage and hence it would generate high energy electrons. In order to reduce the energy of the emitted electrons, the tungsten tip was given -190 V and the copper plate (with a hole at the centre) which is placed at a fraction of a mm away from the tip was given ~ + few kV. So, the emitted electrons coming out through the hole of the copper plate should have kinetic energy of about 190 eV. As the trapping voltage U_{dc} is varied, the axial electron frequency changes and at a certain voltage it becomes equal to the resonance frequency of the tank circuit resulting in the electrons absorbing maximum energy and consequent damping of the circuit. The signal from the tank circuit was sent through a low noise amplifier with input voltage noise density ($\sim 1\, nV/\sqrt{Hz}$) and mixed with a fixed resonance frequency of 60 MHz. The resulting beat frequency spectrum shows prominent dips and a sample of such a dip is shown below along with a plot of ramp voltage (U_{dc}) versus time (Fig. 3).

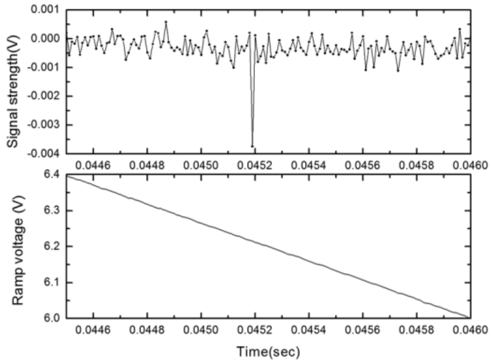

Fig. 3 Representative dip signal

Dips were observed at various trapping voltages U_{dc}, because cylindrical Penning trap creates very small harmonic region and the electrons trapped with amplitude of oscillation greater than the harmonic region in the trap would have different axial frequencies and hence the resonant conditions are satisfied at different ramp voltages. The storage time was estimated from the collision time as about 100 millisecond [3].

Conclusion

It appears that we might have seen the initial signals from the trapped electrons. However, more confirmatory tests have to be done and we are in the process of doing them.

References

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