PENNING TRAP OPTIMIZATION

Ryan Ringle

The primary experimental installation within the LEBIT project is a Penning trap mass spectrometer. Nuclear binding energies far from stability are investigated with high precision via the determination of masses of unstable nuclides. The mass measurement is carried out by determining the cyclotron frequency, $\omega_c = (q/m)B$, of an ion with mass-to-charge ratio q/m stored in a strong magnetic field B. In order to prevent the ions to escape along the magnetic field lines an appropriate electric field has to be employed. The basic electrode configuration of a Penning trap consists of two hyperbolic endcaps and a hyperbolic ring electrode, representing equipotential surfaces of an axial quadrupole. For the trapping of a positively charged ion, a positive voltage is applied to the endcaps and a negative voltage is applied to the ring electrode. The motion resulting from the presence of both electric and magnetic field consists of a superposition of three independent harmonic eigenmotions: the axial motion, the reduced cyclotron motion, and the magnetron motion. The magnetron and reduced cyclotron motions are in the radial direction, while the axial motion is along the z-axis (defined by the magnetic field). These motions are very well understood and its observation allows to determine the cyclotron frequency of the ions. For achieving a high precision a high quality of the storage fields is decisive. The electric field should be a pure electric quadrupole with axial symmetry and the magnetic field should be homogenous.

In a practical design of a high precision trap additional correction electrodes must be added to the three hyperbolic-shaped electrodes. They compensate for the finite size of the hyperbolic electrodes and for holes that have been placed in them for the injection and ejection of ions. An important factor contributing to the magnetic field homogeneity inside the trap is the material susceptibility and shape of the mechanical trap components. For LEBIT we took as a basis the design used at CERN in the ISOLTRAP spectrometer. We analyzed this system and optimized it further.

Figure 1 (left) shows a cut through of the proposed LEBIT trap. The electrodes and support

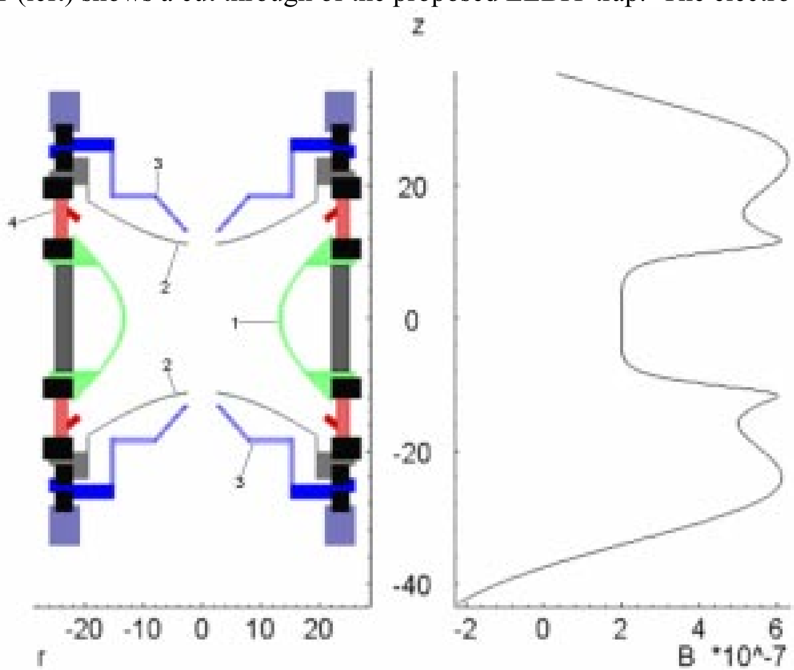

Figure 1: Proposed LEBIT Trap. The proposed LEBIT trap (left). 1 ring electrode, 2 endcap electrode, 3 injection/ejection electrode, 4 correction electrode The black elements are macor, while the colored elements are oxygen-free copper. Contribution of the trap material to the magnetic field along the axis of the trap (right).

structures are constructed from oxygen-free copper, while the insulation pieces are macor. To the right is a plot showing the result of a calculation of this trap s effects on the magnetic field along the symmetry axis of the trap in terms of $\Delta B/B$. The calculation was performed with SUSZI, a program which calculates contributions to the applied magnetic field by summing the fields created by each small magnetized trap element at a given position.

The design changes, such as greater mechanical symmetry and thinner electrodes, as compared to the ISOLTRAP system, improve the magnetic field homogeneity inside the trap considerably. It is important that inhomogeneity contributions are minimized independently for each of the materials used. In this way a precise knowledge of the susceptibility of each trap material is not required. The production of precision electrodes with a thickness of only 0.2 mm is a challenge. The best technique has still to be found, high-velocity electro-forming may be one option.

It is illustrative to study the effect of the magnetic field inhomogeneity on the determination of the cyclotron frequency as a function of the axial amplitude of the ion motion of the stored ion. For this purpose the time averaged relative magnetic field shift is evaluated as a function of the axial amplitude of the ion. This shift is equivalent to the maximum systematic effect $\Delta\nu_c/\nu_c$ in the cyclotron frequency determination that one can expect. The result of such calculations for both the ISOLTRAP and the improved LEBIT configurations are shown in figure 2.

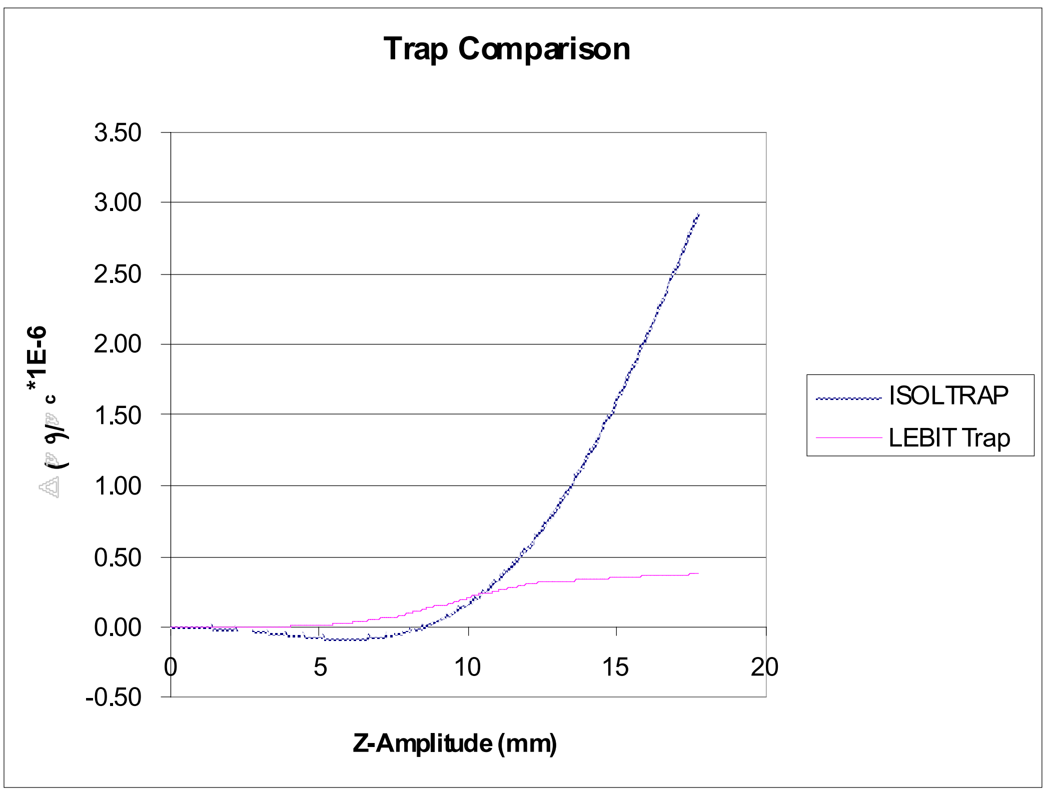

Figure 2. The figure shows that the new design tolerates about twice as large axial amplitudes (~15mm) for keeping the relative frequency shift less than $4{\cdot}10^{-7}$. In the experiment the axial amplitudes are normally not expected to be larger than 5 mm.