Concept of a Modified Quadrupole-Ring-Trap Designed for Laser-Cooling of Crystalline Ion Beams

U. Schramm and D. Habs

Applying laser–cooling on ion beams in storage rings one major aim has been to observe the phase transition of the cooled beam to an ordered Coulomb–crystal [1]. In contrast to similar experiments performed in traps and especially in the quadrupole–ring–trap of the MPQ Munich [2], where ions at rest showed beautiful beam–like crystalline structures, strong heating rates up to now always exceeded the feasible cooling rates in storage ring experiments. Since these heating mechanisms due to shear forces and envelope oscillations strongly depend on the hardly changeable storage ring lattices, the study of criteria for e.g. the stability of a moving beam crystal could be performed in a ring–trap much easier, starting from conditions similar to those known at rest.

We therefore redesigned the existing quadrupole–ring–trap of the MPQ [2] to allow the storage of slowly moving ions. Due to imperfections in the alignment of the quadrupole rods (< 0.1 mm compared to a circumference of ≈ 360 mm and an aperture radius of 2.5 mm) and a contact potential on their surfaces near the atomic Mg oven the electric fields on the beam axis of several 10–100 mV/mm cannot be overcome by the spontaneous laser force ($\lesssim$ 1 meV/mm for Mg^+ ions). The whole ring–trap will be covered with a drift tube like arrangement allowing the acceleration (and optional bunching) of the ions prior to (or while) laser cooling.

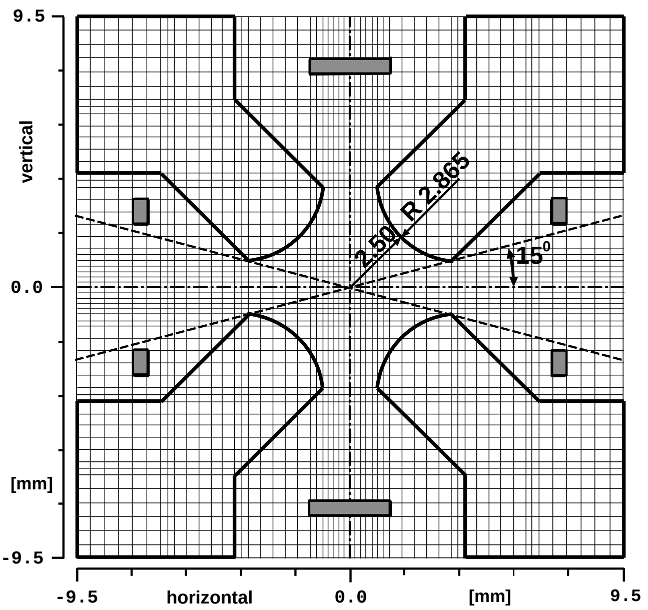

Fig. 1: Profile of the total ring electrode arrangement perpendicular to the direction of ion motion (z-axis). Compared to the minimum aperture radius of the confining quadrupole electrodes of 2.50 mm, the six elements forming one drift tube of the ion acceleration system are placed at an average radius of about 7.5 mm. The thin grid represents the mesh used for the three dimensional numerical field calculations (Mafia [3]) presented in fig. 2.

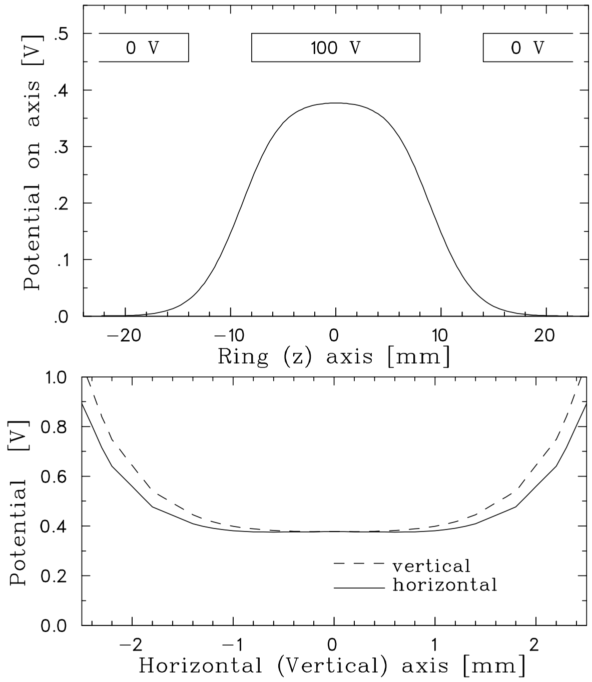

Fig. 2: Calculated penetration of the potential onto the beam axis for a voltage of 100 V applied to one of the drift tubes as indicated by the stripes in the upper frame. The lower frame shows the potential on the horizontal and vertical axis at the middle of the biased drift tube emphasizing the nearly undisturbed symmetry in the center of the trap.

Fig. 1 shows the profile of the standard quadrupole–ring–assembly including the six additional stripes forming one out of e.g. 16 drift electrodes of the projected ion acceleration system. The radial position of these electrode stripes was chosen to achieve a reasonable penetration of the accelerating field onto the beam axis, where the two fold splitting of the horizontal elements guarantees the full 30° opening angle necessary for the manipulation and observation of ions with laser light. For an electrode length of 16 mm and a gap length of 6 mm, indicated in the upper part of fig. 2, a maximum potential on axis of about 0.38 V can be reached with a moderate drift tube voltage of 100 V. The corresponding field strength reaches ≈ 50 mV/mm sufficient to pre–accelerate the ions e.g. by continuously switching the voltage around from one tube to the next.

We hope that this design, presently prepared for construction, will allow a great variety of acceleration and cooling schemes elucidating the actual problems of beam crystallization in real storage rings [4].

References

[1] D. Habs and R. Grimm, Ann. Rev. Nucl. Part. Sci. **45** (1995) 391 and refs. therein.
[2] G. Birkl *et al.*, Nature **357** (1992) 310
[3] T. Weiland *et al.*, Proc. IEEE **PAC84 Vol.5** (1984) 245
[4] U. Schramm *et al.*, this report, p. 49