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THE EXPERIMENT "PUSTAREX" FOR COLLECTIVE ACCELERATION OF HEAVY IONS IN ELECTRON RINGS*

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Abstract

The Pustarex experiment is designed to demonstrate the possibility of collective acceleration of highly charged heavy ions in electron rings to a few MeV/amu in an acceleration length of about 1 m. It employs mainly static magnetic fields, such as must be applied in a practical electron ring accelerator. Only for the compression phase and the transport of the ring to the accelerator does the experiment take advantage of fast pulsed fields. Near the end of compression the electron ring can be doped with ions by passing it through a cluster beam. Between compression and acceleration the ring can be held in a static mirror field, the so-called "Wartesaal" (waiting room), where the heavy ions can be ionized by the ring electrons to high charge states. As the accelerating radial component of the magnetic field is limited to a few 10^{-4} of the guiding axial field the coils had to be built with high accuracy. A few results of pre-experiments and magnetic field measurements are reported. The actual status of the experiment is described including the electron beam system and the vacuum technology.

Introduction

Among the many concepts of collective acceleration of ions the electron ring accelerator is still one of the most challenging and promising as far as the acceleration of heavy ions is concerned. Therefore, after the study of compression of electron rings in Compressor I[1] and the successful collective acceleration of ions in the Schuko experiment of the Garching ERA group[2] it was decided to start a further experiment, that allowed ionization of the heavy ions to high charge states and acceleration of the ions over longer distances and to energies of a few MeV/amu. In addition, this concept should be applicable to a practical accelerator with an acceleration length of a few times ten meters and repetition rates of many cycles/s. This suggested the application of static (or at least quasistatic) magnetic fields which also readily allow a "Wartesaal" to be provided. As the successful fast compression of the rings in the earlier Garching ERA experiments with the resulting increase in the electric field should be retained, the new experiment is characterised by a combination of pulsed and static fields, which somehow helped to find its name "Pustarex".

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The Pustarex Experiment

The Concept of Pustarex

The main element of Pustarex is its static field coil. It consists of 3 parts (see Fig.1): The static coils 1 and 2 form the magnetic mirror for the "Wartesaal" and the diverging field accelerator and coil 3 facilitates

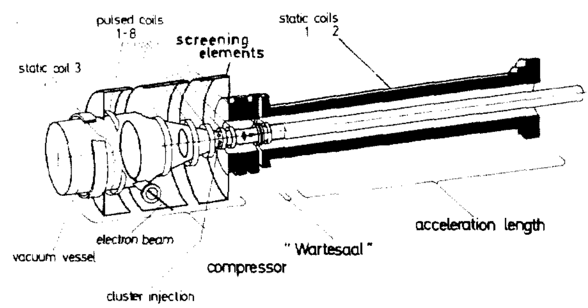

Fig.1: Schematic set-up of the experiment

injection and inflection in a pure static field different from the original concept[3,4]. The pulsed coils compress the electron rings to improve their quality, mainly their internal electric fields, the so-called holding power. Screening elements around the static coils and outside the set of the pulsed coils (not seen in Fig.1) protect the static coils from the penetration of the pulsed fields and in addition prevent asymmetries in the pulsed field, which could be caused by nearby metallic bodies.

The radial component of the pulsed fields pushes the electron ring axially against the static field thus causing energy gain of the electrons and reduction of the ring dimensions. To save energy the pulsed fields are produced by 8 coils, which are fired in sequence. A careful choice of the positions of the pulsed coils 2 and 3 ensures a very rapid crossing of the potentially dangerous betatron resonances at n = 0,2 and n = 0,1. Fig.2 shows the computed dependence of the major radius R, the

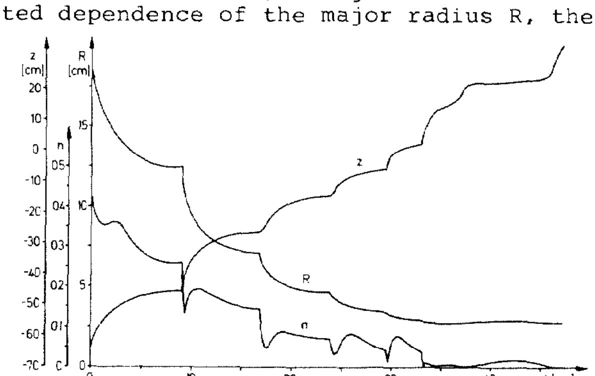

Fig.2: Compression cycle till spill-out for the case without stop in the "Wartesaal"

field index n and the axial position of the ring z (zero for z is set at the left end of the static coil 1) on the field of the pulsed coils as a function of time after injection. In these calculations the effect of the screening elements has been taken into account.

At an axial position between pulsed coils 4 and 5 it is planned to inject two cluster beams. The electron ring, crossing these beams is doped with ions, whose number depends on the size and density of the cluster beams.

In the mirror field of the "Wartesaal" the ring can be parked for several milliseconds, while the electrons of the ring (their energy is ~ 15 MeV) ionize the trapped heavy ions to the desired ionization state.

Essential for the whole concept is a low base pressure of ~ 10^{-10} torr. Only then is background ionization negligible and only then are recombination processes seldom enough to permit high ionization equilibria.

Appropriate conducting or nonconducting walls, inside and/or outside the ring, not shown in Fig.1, are to reduce the coupling impedance of the ring and provide additional focussing. While the ring loses energy owing to synchrotron radiation in the "Wartesaal" and reduces its radius, one of the pulsed coils moves the ring slowly along conical walls towards the spill-point. After the ionization time, the pulsed coils 7 and 8 push the ring to the static field expansion accelerator, where the small radial field component provides the Lorentz-force in axial direction.

The Static Coils

As the accelerating radial component of the magnetic field is only of the order of a few gauss compared with almost 20 kgauss of axial field, and as field asymmetries in the "Wartesaal" and roll-out area, might lead to $\nu_R = 1$ resonances and deterioration of ring quality, the coils were built with very small tolerances. To avoid l = 1 azimuthal asymmetries of the coil ends and their current leads, the coils form bifilar windings with their ends 180° apart. The current lead has a cross-section of 8 x 8 mm^2 with an internal bore for water cooling. With current pulses of 2 kA and 2 s duration repetition times of about 2 min are possible. The coils have 8 to 12 current layers, separated from each other by epoxy layers. The positions of the windings in the epoxy layers were carefully machined to avoid systematic deviations as much as possible. The gap between coil 1 and coil 2 provides the "Wartesaal" and space for the current leads to the pulsed coils and for diagnostic elements.

Static coil 3, which is needed for ring formation is less accurate. By axial shift of this coil the injection parameters (field index n, injection beam energy, axial position) can be slightly changed.

Two additional low-current coils inside the long one help to smooth and vary the radial field component. The first one adds or subtracts a radial field so that a constant value of the radial field over the acceleration length is obtained. Fig.3 shows the

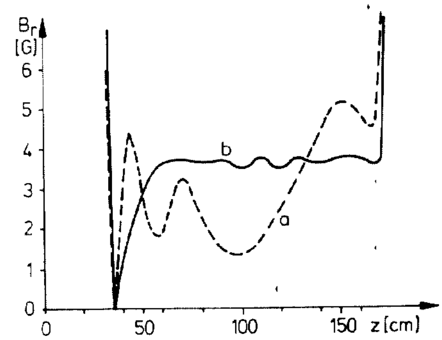

Fig.3: Radial accelerating field with and without corrections

calculated radial field component with and without the first correction coil. The second correction coil adds or subtracts a constant radial field so that accelerating fields of only 1 to over 10 gauss are possible and the experiment therefore gains flexibility for acceleration experiments.

The static coils are now assembled. The axial field in the "Wartesaal" and acceleration area without correction coils has been measured and it agrees in its axial dependence within 2 x 10^{-4} (measuring accuracy) with the calculated field (see Fig.4). The small deviations in the "Wartesaal" area almost disappear, when coils 1 and 2 are moved 0,1 mm closer together. Axial field disturbances on the injection orbit are less than 3 x 10^{-3}.

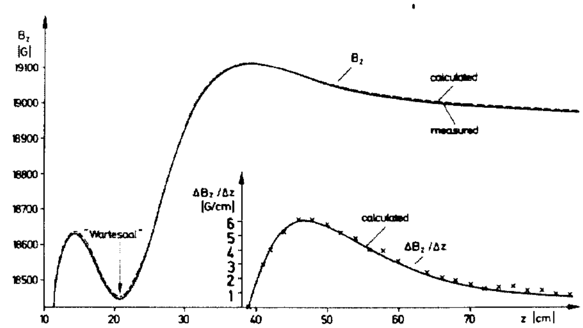

Fig.4: Calculated and measured axial field and its gradient

The Pulsed Coils

The eight pulsed coils are single-turn coils wound from a 3 to 5 cm wide Cu ribbon. They are connected via spark gaps to capacitors and charged to 30 kV. As the coils are fired in sequence, special spark gaps had to be developed to prevent prefire caused by the coupling of the coils. The present arrangement of the pulsed coils is seen in Fig.1. The concept of Pustarex allows many changes in the arrangement of the coils. Fig.5 gives the currents in the coils as a function of time calculated for the case that the ring does not stop in the "Wartesaal". The pulsed coils compress the ring and move it axially. The pulsed coils 2 and 3 provide very rapid crossing of the potentially dangerous resonances at n = 0,2 and n = 0,1 (see Fig.2). The first coils were tested and installed.

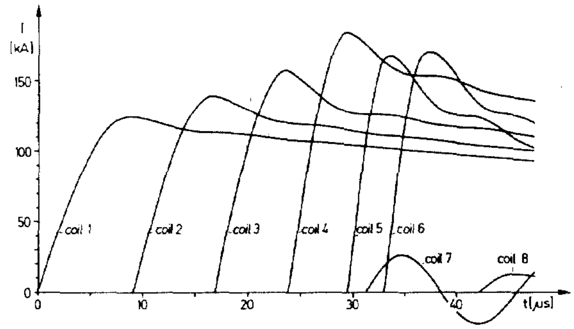

Fig.5: Currents in the pulsed coils for the compression cycle of Fig.2

The Screening Elements

Copper screens around the pulsed coil system prevent disturbances in the pulsed field due to nearby metallic bodies. In addition they protect the static coils from the flux of the pulsed coils. For the thickness of the screen a compromise had to be found between protecting the static coil and penetration of the static field during the 2 s pulse. The deviation of the quasistatic field from its asymptotic value should be less than 10^{-4}. From computer calculations a thickness of 5 mm appeared to be a good compromise. The eddy currents in the static coil itself were not taken into account. Measurements of the field penetration showed that after a pulse length of 1.4 s the deviations from the asymptotic value were less than $2\cdot10^{-4}$ (limit of the measuring accuracy). On the other hand, the penetration of the pulsed fields into the static coils is expected to be negligible even for a few hundred microseconds current decay time. Measuring of the inductance of the screened static coil showed that the inductance tends towards a constant value below 1 Hz and drops rapidly for higher frequencies.

Vacuum Vessel and Cluster Beam

For the first phase of the experiments with adjustments and even for experiments to accelerate light ions, the "Wartesaal" is not needed and the vacuum requirements are reduced. For these purposes a Kapton covered epoxy vessel was manufactured and pressures of almost 10^{-8} torr have been achieved with nitrogen cooling. The vacuum of this vessel is limited by the permeation of water vapor from the outside. For lower pressures glass vessels are prepared.

The behaviour of cluster beams has been studied. Sharp-edged beams could be produced and their density and cluster size could be varied in a wide range. The question whether the cluster breaks down during ionization needs to be studied. For more details see[4].

Injection and Inflection

In pre-experiments[5] injection and inflection into a static field was studied. The electron beam guiding system is an iron pipe to shield the beam from the static field. As the electron ring after injection stays close to the iron injection snout for many turns, the field disturbance caused by the snout has to be compensated. This was done by currents on the snout surface, the distribution of which is shown in Fig.6, where the conical part of the snout is developed into a plane.

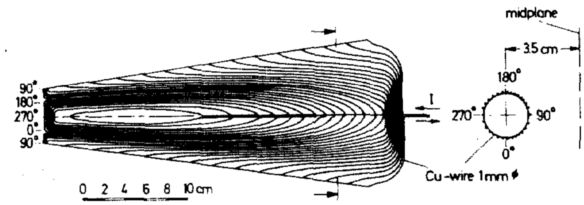

Fig.6: Development of the current layer of the conical injection snout

With this current distribution the field deviations on the injection closed orbit were less than ± 0.5%.

Axial inflection seemed appropriate to Pustarex with its larger axial than radial motion. No differences in the final trapped particle numbers were seen between axial and radial inflection in a separate experiment[5]. $8\cdot10^{12}$ electrons were inflected but only half of them being trapped for longer times, presumably because of the negative mass instability. Therefore, improvements in the electron beam system (larger energy spread, energy ramp, higher phase space density) will be aimed at parallel to the Pustarex compression and acceleration experiments.

Summary

The experiment is still being assembled. The static magnetic fields are equal to the calculated values within the limits of the measuring accuracy. Injection and formation of the electron ring have been studied in a separate experiment. The vacuum vessel and the electron gun with the beam line are ready to be connected and put in place. If it is possible to obtain multiply charged ions and accelerate these to a few MeV/amu in an acceleration distance of not much more than 1 m in the Pustarex experiment, it is expected that the earlier mentioned extensions lead to a practical heavy ion accelerator.

Acknowledgements

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