RECENT EXPERIMENTS ON ERA IN KARLSRUHE

C.-H. Dustmann, H. Krauth, L. Steinbock, W. Zernial

Institut für Experimentelle Kernphysik der Universität
und des Kernforschungszentrums Karlsruhe, Germany

Abstract

The experiments on ERA in Karlsruhe are reviewed. A new compression coil system including devices for roll out, spill out and expansion acceleration is under construction. Two possible applications of a molecular beam source for heavy ion and cluster ion acceleration are proposed.

Old coil system

The experiments on ERA at Karlsruhe have been up to now carried out with a 3 stage Helmholtz-compressor designed 4 years ago which was changed only a little in the following time.[1,2] The electron rings are formed at $R \approx 20$ cm and are compressed down to radius of $R \approx 3$ cm with an energy $E \approx 16$ MeV. By varying the times of switching the coil currents and by changing the axial distance of the coils several compression programs with different n-patterns could be tested.

As main diagnostic tools magnetic pick up loops are used to measure the number of electrons and to detect possible losses during the inflection and compression process. With a fast loop (working in the nsec-region) it could be shown that up to one half of the injected electron pulse with a length of 12 nsec could be inflected. By a suitable choice of the compression program nearly all these electrons could be compressed down to 3 cm. But small losses occured sometimes at n = 0.5, 0.25. In fig.1 a typical signal of the slow pick up loop is shown. A positive bump can be seen in the negative $\dot{B}$ signal due to the compression of the electron ring. This bump indicates a loss of some electrons. The loss could be explained by a blow up during the crossing of the n = 0.25 resonance. This resonance was driven by the relatively high field disturbances of the compression coils in these experiments. A further blow up was caused by the multiple crossing of the Walkinshaw resonance at n = 0.2.

Obviously the influence of single particle effects were dominant in this set up. But the occurence of some collective effects could not be excluded, especially in the first compression stage. The fact, that signals with the frequency $\omega = \omega_c$ and $\omega = (1 - \nu_r)\omega_c$ could be measured, indicated that some azimuthal bunching and also transversal deformation existed.

The maximum number of electrons compressed down to the final radius was about $2 \cdot 10^{12}$. Because of the big values for the minor radii (measured with scrapers and x-rays as well as with synchrotron light) caused mainly by the single particle resonances only a holding power of about 5 MV/m could be reached. Therefore a new design of the coil system is made which is described in the following section.

New coil system

The new coil system (fig. 2) is optimized with respect to single particle behaviour. The coils have another winding structure so that the field distortions are small. To cross the critical n-values far away from the injection snout the field index is kept at a relatively high value of about 0.4 at the inital stage of compression and all the resonances are crossed at small radii. Moreover this relatively high field index provides a good Landau damping coefficient for the negative mass instability during the initial stage when γ is still small. A special "n-coil" is used to cross the critical n values very fast. And also, choosing the parameters of this coil in a proper way, we can obtain the second derivative of the field $\partial^2 B/\partial r^2 \approx 0$ at n = 0.2 so that the driving force for this resonance is made small.

Further compression is done by coil pair II. Coil III and coils IV 1, 2, 3 are planned for roll out and spill out. A 65 cm solenoid should allow for expansion acceleration of the ion loaded ring. B_ρ-coils are used to adjust the accelerating B_ρ-field.

During the last months the first stages of this new arrangement were assembled. Coil pair 1a and 1b are fired in series to get the nearly constant field index. Again about 10^{12} electrons could be inflected. But it turned out very soon that a severe loss occured at a radius $R \approx 13$ cm. Only a few times 10^{11} electrons survived this instability. At this radius the Landau damping coefficient $\Delta S \cdot E/\Delta E$ of the first mode of the transverse radial instability had a small value due to the behaviour of the field index at this radius. The firing of the n-coil before this critical point was not enough to change the field index shape and did not make a substantial improvement. The observation of a strong signal of $\omega = (1 - \nu_r)\omega_c$ convinced us that the loss was due to the radial instability. To get some more information about this instability a 3 Ω/square foil was installed 4 cm away from the compressor median plan. But this foil had no noticeable effect on the stability of the ring. The main effect of this foil was an increase of the selfinflection to a value of about 30 % of the electrons inflected with inflector on ($2 \cdot 10^{12}$ with about

50 A injected). It seems to be that we need more care of the transverse instability in this first stage of the compression system even at the intensity of $2 \cdot 10^{12}$ electrons.

Field emission tube

The main reason for the small current injected in the compressor is in the poor beam quality of the commercial field emission tube of the FEBETRON 705. In order to improve the beam quality we made some studies on the electron tube. The new tube works without magnetic focussing. Therefore the accelerating gap between cathode and anode is kept small (3 - 4 cm). To reduce space charge effects, the electron current from the cathode is made smaller and the main current of the Marx generator flows through a shunted $CuSO_4$ resistor. After some problems to operate a first version of a selfmade tube at full voltage (2.3 MeV) because of damages of the epoxy-insulators due to electron bombardment from the cathode electrode we constructed a tube with the geometry shown in fig. 4. The total output of this tube is about 600 A, the usefull current is about 200 A (compared to 6000 A and 40 A respectively in the commercial tube). Emittance and energy measurements are planned prior to assembling the tube in the electron ring experiment.

Ion loading

Besides the above attempts to improve the quality of the electron rings an apparatus is being prepared to carry out ion loading experiments with the aid of the molecular beam device proposed at the 4th work meeting on electron ring accelerators.[3] To reach the required vacuum of 10^{-8} torr or better a quartz glass chamber has been developed in cooperation with the industry. It consists of three viton sealed quartz pieces. In test runs we could reach a vacuum of about 10^{-8} torr.

By use of the proposed apparatus all gaseous materials can be used for ion loading and ion acceleration. The loading process can be controlled over a wide range by varying both the loading time and the intensity of the molecular beam. An important phenomenon in the generation process of these beams is the condensation of the molecules during the expansion in the pulsed nozzle source.[4] This condensation of up to some 10^4 molecules forming small drops of a liquid is accompanied with a partial monochromatisation of the beam and provides good geometrical properties. But no experience is available about the interaction of such clusters with relativistic electrons and especially with dense electron rings. Therefore experiments are necessary in the future.

Two applications of a electronring-cluster-beam device are possible - supposed that electron rings with holding powers of say 50 MV/m are available.

1. If a sufficient long ionisation time between ion loading and expansion acceleration is provided ($T_i > 100$ µsec), all clusters are fully broken up and the atoms are multiply ionized. In this case the device can act as an ion accelerator with a small loading fraction $N_{ion}/N_e \approx 10^{-3} - 10^{-2}$. Acceleration can be done up to energies in the region of 10 MeV/nucleon. An application can be found for example in heavy ion physics or the irradiation of materials.
2. Another possibility is - as pointed out also by Bottiglioni[5] - to accelerate the cluster as a whole, each cluster being ionized only a few times, in order not to neutralize the electron charge. Even multiply charged clusters are stable as shown for example by Henkes.[6] Considerable amounts of particles can be accelerated.

$$\left(\frac{N_{atoms}}{N_e} \approx 10 - 100,\ 1 < \frac{N^+}{N^-} \leq 10^{-1} \text{ for } H_2\right)$$

Because of the high mass loading the energy gain is very small, for example 10 - 100 keV/atom. An interesting possible application of such a device is the injection of the accelerated clusters of hydrogen molecules in fusion power systems.

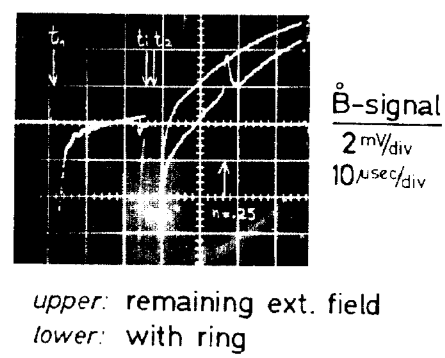

Fig. 1: Example of a self field measurement showing a small electron loss at n = 0.25

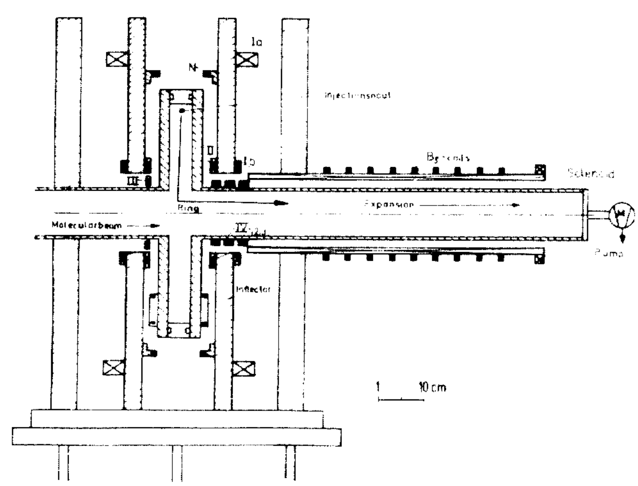

Fig. 2: New compressor geometry

References

1 C.-H. Dustmann et al., Proceedings of the 8th International Conference on High-Energy Accelerators, CERN 1971, p. 408 - 414

2 C.-H. Dustmann et al., Int. Symp. on Collective Methods of Acceleration, Dubna 1972

3 H. Krauth, Proc. of the 4th Work Meeting on ERA, Garching 1971

4 E.W. Becker et al., Zeitschrift für Naturforschung 17a (1962) 786

5 F. Bottiglioni et al., Nuclear Instr. and Methods 106(1973) 127

6 W. Henkes et al., Int. Journ. Mass Spectr. Ion Physics 5 (1970) 249

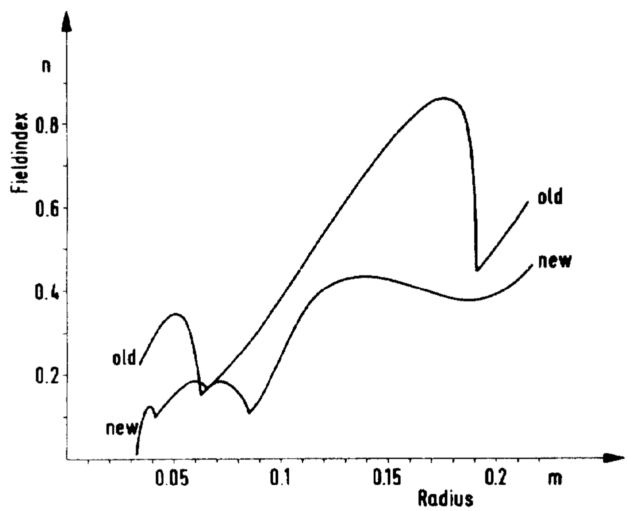

Fig. 3: Fieldindex n as a function of R in the old and the new set up

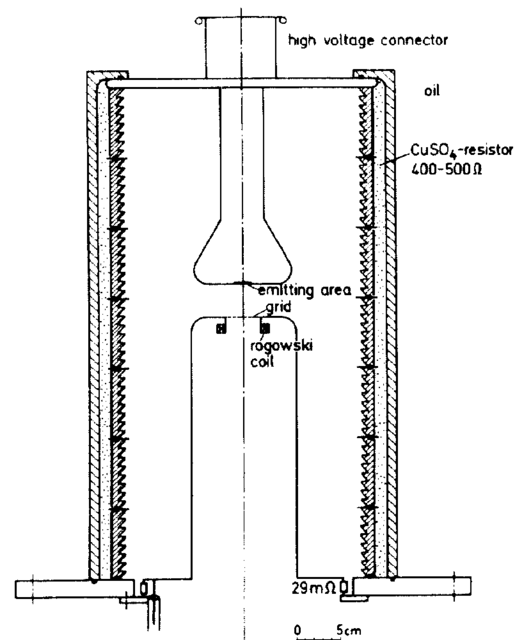

Fig. 4: Fieldemission tube