STATUS REPORT ON ERA-KARLSRUHE

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(presented by H. Herman)

Abstract

The first stage of the Karlsruhe experimental ERA program is described. Preliminary results with compressed electron rings are presented and discussed. Future plans are submitted.

A. Intention of our ERA program

Our engagement in using the ERA principle for a heavy ion accelerator dates back to the beginning of this group. It was clear that any research in this field presumed the availability of a compressed electron ring. After this goal has been reached we are able and willing to take over the responsibility for the development of special components of such a big project.

Whatever difficulties may still arise it is true for each laboratory in this field and its corresponding concept that ring brightness has to be raised and repetition rates have to be increased considerably in order to compete with plans for conventional heavy ion accelerators. Cooperation between the groups in this field seems necessary to solve the problems in finite time. Karlsruhe ERA research group will put its main effort in developing a high-repeating-compressor. A special paper to this topic is presented at this conference [1].

B. Injector and beam line

As an injector we use a commercially available field emission machine: Febetron 705. An earlier paper goes into details of the machine and describes its beam quality [2]. Former hopes to take advantage of its enormous output power (see Fig. 3) by relatively slight changes on the hardware could not be realized. We succeeded in operating a window less field emission tube but the brightness of the useful electron beam could not be raised considerably. Furthermore we found that reproducibility of the electron pulse requires high quality vacuum which is for the moment not possible in connection with our epoxy vacuum chamber.

For the moment an improvement program is going on trying to shape the field pattern of the acceleration path of the emission tube by a Pierce optics. A second Febetron is available for these studies. The intention is to improve the beam quality at least to a level where studies of collective effects during compression and expansion experiments with this generation of compressor become possible. We are aware that the Febetron will not be the injector of a future heavy ion accelerator - simply because of the restricted repetition rate of its Marx generator.

On the beam line we have changed over from quadrupole focusing to solenoids. We found the reason not in physics but in the ease by which solenoids are handled and adaptable to every days modifications.

C. Inflection

Inflection apparatus proved for a long time to be the crucial problem for us in producing satisfactory rings. Our usable electron pulse is very short and comparable to a single revolution time in the compressor (see Fig. 4), on the other hand the total jitter of the source is large. Therefore it was clear that the trigger for the inflector pulse had to come from a stage, from where on jitter was below 1 nsec. We chose the second stage of the electron source Marx-generator as trigger source. It delivers a 70 kV pulse into 50 Ω. From there on we had a maximum of 120 nsec left for synchronisation, spark gap firing, and cable transfer of pulse (at least 105 nsec). The remaining time for active elements is 15 nsec. Considering this short time we decided on a single spark gap as switching element for the inflector pulse.

The first concept as presented at the 4th ERA meeting in Munich [8] was based on a short 45° inflector within the compression chamber. The intention was to give each electron a single kick, passing the closed orbit. From a theoretical point of view and keeping in mind that our injector allows only for single turn injection we expected from this single turn inflection advantage with respect to the emittance of the ring. The concept called for a very short pulse fall time and high pulse current. The first requirement could be satisfied by feeding 10 small sub-inflectors separately by 10 × 50 Ω coax cables. They presented a load of 5 Ω to the spark gap. The gap could be brought to a resistance of 3 Ω within 2 nsec. Calculations showed that the voltage for the charged coax cables had to be about 100 kV or higher. Experimentally, however, it was not possible to go considerably beyond 50 kV with normal insulation techniques at the small dimensions for the switch, required to keep defined connections for the coax cables. We finally decided on SF_6 as insulating gas for the gap and the complete dc side of the switch. We tried several methods to eliminate the reflected pulse from the inflector inductance. Termination of the cables at the inflector side with additional carbon resistors proved to be the cleanest solution if one accepts to lose half the inflector power.

The switch and the described inflector produced 4 Gauß/nsec at 30 kV charging voltage. This is not enough for a 45° inflector to pull the total input from the snout, but part of it should have been inflected. However no acceptable ring, but an X-ray signal ranging up to 5µ sec after injection was observed. A 45° outer inflector, driven by a 90 kV pulser and essentially the same circuit produced the first poor rings. A 180° outer inflector finally brought the results shown in Fig. 9, 10, 11. To check the suspected influence of the geometry of the 45° inflector on the ring stability, we put it as a dummy in addition to the active 180° inflector on the compression chamber. The ring diminished to very small intensities.

D. Coil system and compression cycle

Our coil system and its motivation is described in earlier papers[3,4]. A strong resonance at R = 18 cm (n = 0.36) caused heavy losses and forced us to change our compression program. The snout - which is best compensated for a later time (see Fig. 5)[5] - in connection with a 90° axial symmetry of the vacuum chamber's metal fittings, evidently causes enough field distortions at R = 18 cm so that the ring blows up. The resonance of n = 0.36 is especially sensitive to 90° symmetrical distortions. The easiest way for us to cross the 0.36 resonance later was to fire coil II just before this critical point. Coil II is not suited well for field index shaping at this large radius if one still expects some compression power from it. Its circuit could only be driven with 24 kV instead of 30 in order to keep the field index below 1 nevertheless one had to accept a steep rise of n through several other - seemingly unserious - resonances. Because of the reduced compression power of coil II, circuit III had to be fired earlier too and with reduced power. Again a steep rise of n must be tolerated. The compression program is shown in Fig. 1 and 2. The field index pattern shows that it certainly is not the state of the art, and it should be regarded as preliminary until the driving forces of 0.36 resonance caused by the vacuum hardware are reduced. Only if this should fail we shall use a special circuit on coil I for n-shaping.

In spite of the reduced voltages in the condenser banks it was possible to compress rings down to R = 3 cm radius. The energy was calculated to rise from $\gamma = 5.4$ to $\gamma \approx 30$. Full power to the compressor coils shall reduce the big radius to 2.5 and rise the energy to about $\gamma = 45$.

E. Experiments with the ring

As ring detectors we have so far used X-ray multipliers and Faraday cups. With radially and axially moveable scrapers we produce X-ray signals which are detected by a strongly collimated detector. The detector is moveable from R = 25 down to R = 0 and resoves the X-ray source to 1 cm (Fig. 12). This is especially helpful for identifying beam losses in the early stage of compression where radius and field index vary fast in time. X-ray signals measured with this detector are shown in Fig. 9, 10, 11. Fig. 9 shows the total compression time from injection to the destruction of the ring at 4 cm by a cylindrical scraper. The signal is very short because the ring is lost very fast on the metal cylinder. Fig. 10 shows in its upper part a comparably long lasting destruction act, caused by a Faraday cup at the same radius as the cylinder. In the lower part one recognizes the corresponding electrical signal. The left-hand picture shows the loading process of a cable capacity by the ring, the right one shows the direct current of electrons hitting the cup. Fig. 11 shows measurements of the small ring diameter. We found a mean diameter of 2 mm at R = 3.8 cm. The smallest major diameter to which we could identify the ring was 3.0 cm. The number of particles was determined by the Faraday cup method to about 10^{10}. It was instructive to follow back the ring to its larger major radii. In Fig. 2 we see for large R a severe deviation of the theoretical compression program from the real behaviour of the ring. The reason for this might be that the scraper produces field distortions which are especially severe in our preliminary compression program at big radii. Because of resonance blow up the ring hits the scraper earlier than it should.

F. Vacuum system and ion loading

The ion loading system was presented in an earlier paper [5]. The method of loading by a sharply collimated molecular beam which is ionised and trapped by the ring has advantages only if it is possible to reach a vacuum better than 10^{-8}. Up to date we are using compression chambers consisting of an epoxy ring covered by two glass plates (Fig. 13). A turbomolecular pump TVP 900 produces a vacuum of 10^{-6} within the chamber. This is not enough to keep a clean ring during compression. Earlier plans provided for an Al_2O_3 chamber. Because of manufacturing difficulties in Europe we had to cancel this chamber in favour of a quartz glass version which is in construction. Loading experiments can start as soon as the required vacuum is available. Tests of the loading apparatus without ring have provided the beam profiles shown in Fig. 14.

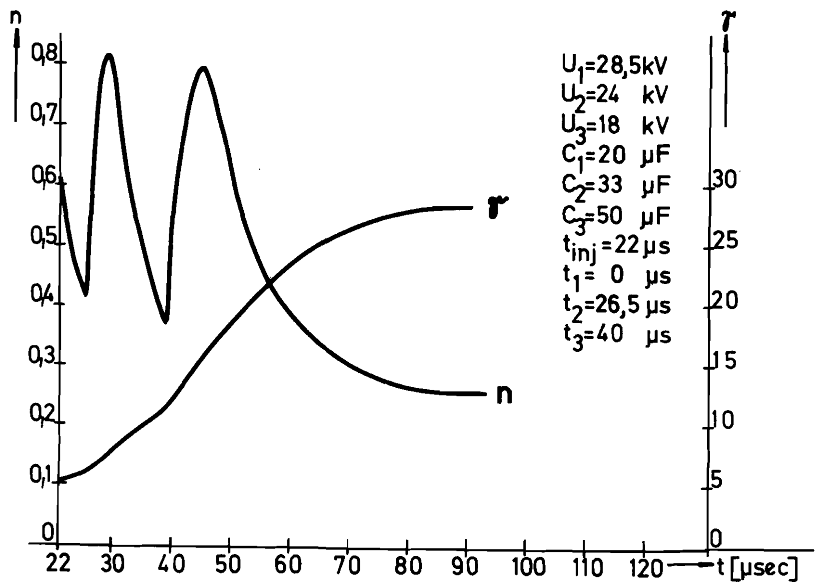
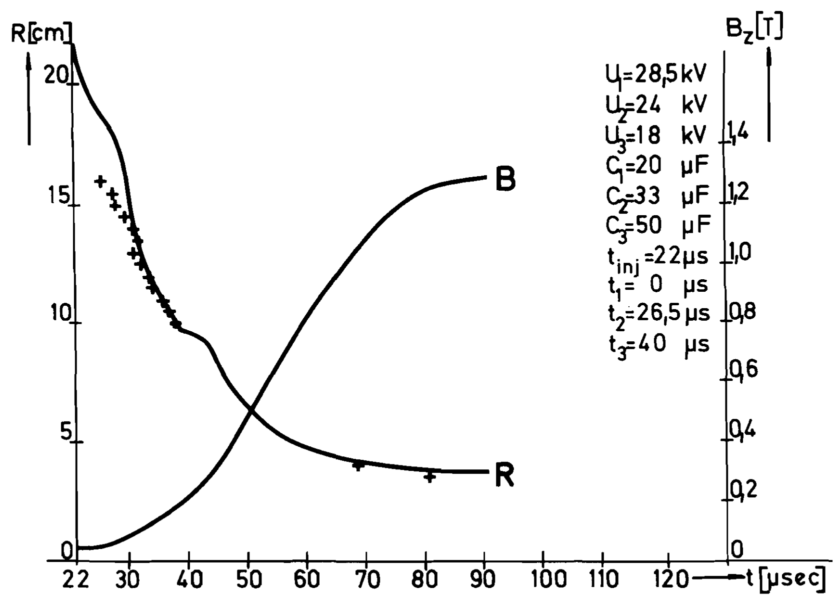


Fig. 1: Field index (n) and energy (γ)



Field 2: Magnetic field (B_z) and radius (R) with experimental results (+)

List of parameters of existing hardware

Injector: Febetron 705

(Field emission with very broad energy spectrum and large emittance)

max.current	~ 6000 A
max.energy	~ 2.3 MeV
pulse length	~ 100 nsec

Injected electron beam:

current:	10 - 40 A depending on ΔE/E
pulse length:	ca. 8 nsec
emittance:	0.1 cmrad
energy:	2.2 MeV
ΔE/E:	± 3 % at 10 A output

Beam guiding and matching system:

3 m long beam line with 5 solenoids and 2 steering coils

Snout:

acceptance:	0.1 cmrad matched to the injection field index 0.5
length:	50 cm
opening:	2 cm diameter at compressor end
material:	armco iron 0.5 mm plated with 0.1 mm copper
field inside:	10^{-3} of outside field during first 40 μsec after firing of coil I
outside field distortion:	$< 10^{-2}$ during first stage of compression at R = 20 cm

Inflection system:

180° outer inflector centered at 135°

dimensions:	680 mm × 40 mm
construction:	1 turn of 1 cm broad copper sheet connected in series with 200 Ω carbon resistor at each side of chamber (10 cm apart). Each turn is driven by a cable transformer of 4 × 50 Ω coaxial cables.
switch:	Triggatron spark gap, 2mm gap isolated by 10 atü SF_6.
trigger:	70 kV puls from electron source

synchronisation with electron puls:

variation of pressure in electron source Marx-generator.

efficiency of switch:	90 %
jitter:	1 nsec
decay time of pulse:	15 nsec (with inflector load)
inflection power:	$\dot{B}$ = 3 Gauß/nsec

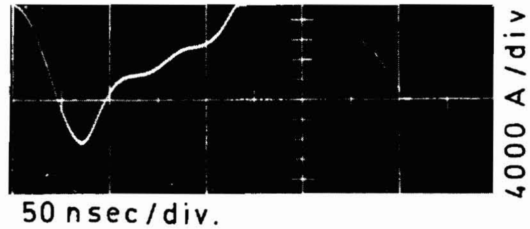


Fig. 3: Electron pulse from the Febetron

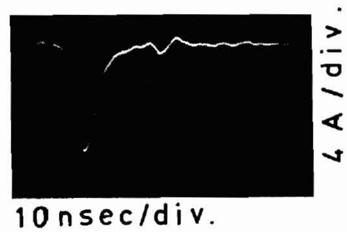


Fig. 4: Injected electron pulse

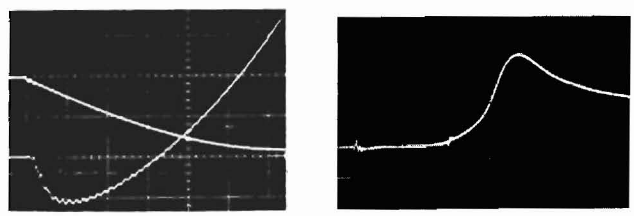


Fig. 5: Snout compensation
Left, upper: outside field, vert.: 100 mV/div
lower: outside field distortion, vert.: 1 m/div
Right: inside field 10 cm from the end of the snout
horiz. sensitivity 20 μsec/div

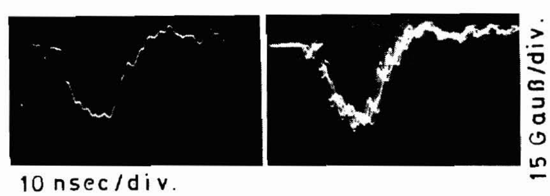


Fig. 6: Inflection field

Magnet system:

3 stage Helmholtz-compressor without additional n-shaping circuits. Coils wound in 2 layers of 10 mm copper wire and inbedded into fiber glass epoxy.

coil system I: w_1 = 2 × 6 windings
$\bar{R}_1$ = 34.2 cm, $\bar{z}_1$ = 31 cm
L_1 = 80 μH

coil system II: w_2 = 2 × 6 windings
$\bar{R}_2$ = 16.4 cm, $\bar{z}_2$ = 16 cm
L_2 = 37.4 μH

coil system III: w_3 = 2 × 8 windings
$\bar{R}_3$ = 7.4 cm, $\bar{z}_3$ = 9 cm
L_3 = 17.1 μH

tolerances: variation of field B_z along one revolution $\Delta B_z/B_z < 5 \times 10^{-4}$ for all coils

circuits are switched and crow-barred by spark gaps.

Circuitry for the compression cycle referred to in the text:

capacities: C_1 = 20 μH
C_2 = 33 μH
C_3 = 50 μH

loading voltage: U_1 = 28.5 kV $\pm\ 10^{-4}$
U_2 = 24.0 kV
U_3 = 18 kV

max.currents: I_1 = 14 kA
I_2 = 23 kA
I_3 = 31 kA

switching times: τ_1 = 0
τ_2 = 26.5 μsec
τ_3 = 40 μsec

Power supplies allow for 1 Hz operation.

Ring compression program for above parameters:

$\gamma_{injection}$ = 5.4
$R_{injection}$ = 23.5 cm
$\tau_{injection}$ = 22 μsec
first closed orbit = 21.5 cm (B=425 Gauß)
R_{fin} = 3.0 cm (measured value)
r_{fin} = 0.2 cm (measured at R = 3.8 cm)
γ_{fin} = 28 (calculated)
N_e = ca. 10^{+10} electrons (measured)

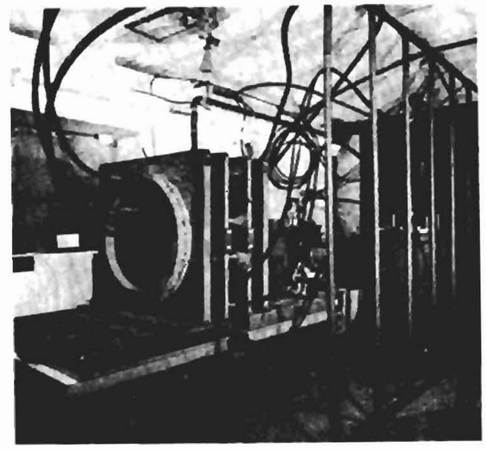


Fig. 7: Electron ring compressor

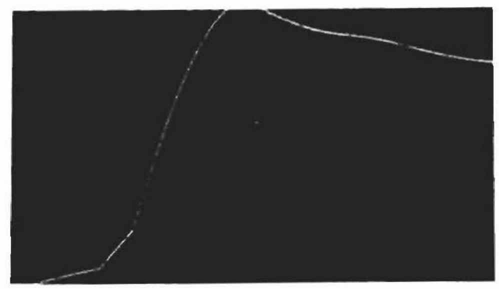


Fig. 8: Magnetic field in the center of compressor (20 μsec/div)

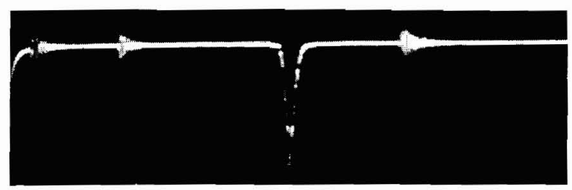


Fig. 9: X-ray from injection and at R=4.0cm (horiz.: 20μsec/div)

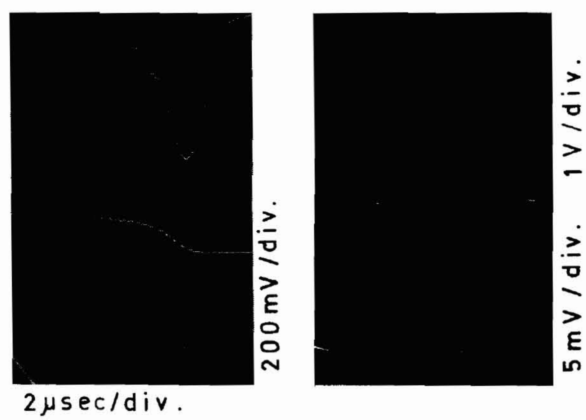


Fig. 10: Upper: X-ray signal at R=3.5 cm
Lower left: collected charge of the ring
Lower right: current signal on the Faraday cup

Diagnostic system so far tested:

scrapers: moveable from large radii to R=0.
moveable for 4 cm in axial direction.
scrapers are partially connected to Farady cups.

x-ray detectors : collimated detectors using multipliers with NaJ crystals and Ne 103 plastics.

Vacuum system:

beam guiding system: stainless steel (10^{-7} torr)

compression chamber: cylindrical epoxy ring covered on the sides with 15 mm glass plates.

sealing: viton

pressure: 10^{-6}

pumps: 2 x turbomolecular pump TVP 900

Ion loading system:

method: supersonic molecular beam adequately shaped to the electron ring.

vacuum required: p smaller 10^{-8} torr.

ions: all gaseous material

molecular beam intensities: 10^{16} to 10^{19} per cm^2sec.

loading time: t = 100 µsec.

References

1) Steinbock,L. Some remarks on future compressors.Report to be presented at the VIII International Conference on High Energy Accelerators.

2) Dustmann,C. Experiences with the Febetron.(KFK,Ext.Ber.3/69/30)

3) Kappe,P. The Karlsruhe Compressor (KFK Ext.Ber.3/69/30)

4) Kappe,P. Field error due to the intrinsic winding structure of multi winding high power Helmholtz coils.(IPP 0/3)

5) Hermann,H. Injection snout compensation (IPP 0/3)

6) Krauth,H. Molecular beam apparatus for defined loading of the electron ring.(IPP 0/3)

7) Kappe,P. Self field effects during the expansion of an ion loaded electron ring.(see 1)).

8) Zernial,W. Status report on Karlsruhe ERA project.(IPP 0/3)

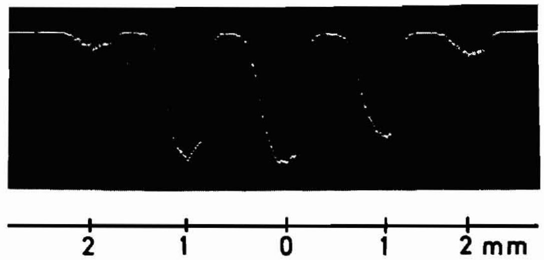


Fig.11: Profile of the ring in z-direction at R=3.8 cm.

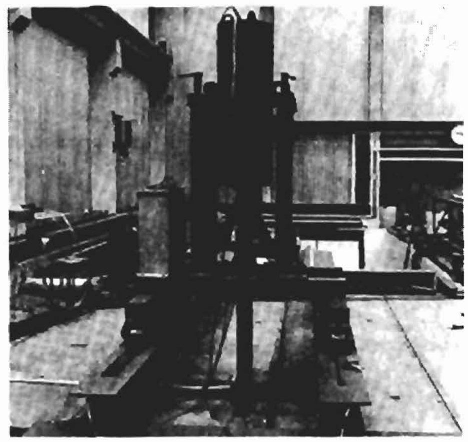


Fig.12: Moveable x-ray detector above compressor

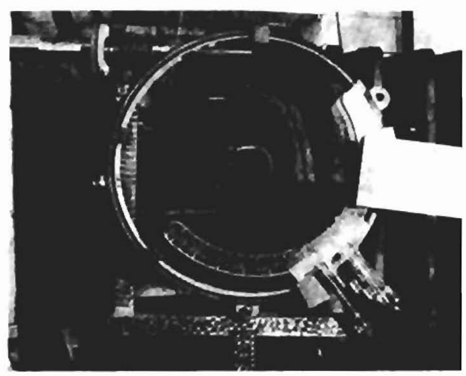


Fig.13: Vacuum chamber with inflector.

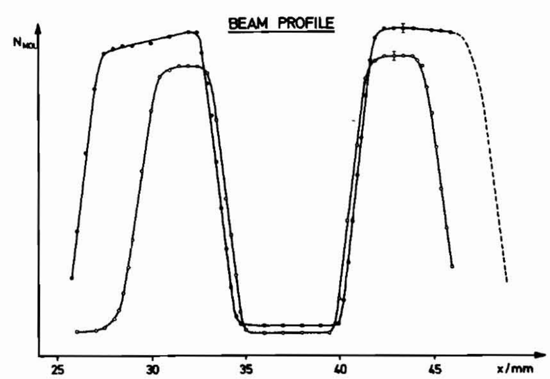


Fig.14: Profile of the molecular beam.

DISCUSSION

T.K. KHOE : If one were using an ERA as a heavy-ion accelerator, what would be the repetition rate (for a given number of electrons per ring) to obtain 10^{11} heavy particles per second ?

H. HERMANN : The number of possible ions in a ring depends,besides other facts, on the quality of the ring (dimensions) and the expansion rate, but also on the kind of ions. So the answer to the question cannot be a number which holds in general. But to give an idea, if we used protons in a ring of 10^{13} electrons, one would need about 1 Hz operation.

A.U. LUCCIO : What kind of ions do you plan to inject into the ring with your molecular-beam apparatus ?

H. HERMANN : The apparatus accepts all kinds of gaseous material. However, other reasons, for example the holding power of the ring, might restrict us to certain materials.

H. SCHOPPER : In a heavy-ion accelerator, it is important to control the loading of the ring since the final energy of the ions depends on the ring loading. Therefore, as has been mentioned, an ion-beam device has been developed at Karlsruhe for this purpose. All atoms that can be put into an ion beam can, therefore, be injected into the ring.

May I now ask if there are any new results on self-inflection, a subject that was discussed at previous conferences ?

D. KEEFE : No.