MEASUREMENTS OF ELECTRON RING COMPRESSION IN THE GARCHING ERA
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Introduction
In electron ring experiments the main purpose of the compressor is to increase the holding power by adiabatic compression of the ring dimensions. Experimental efforts are therefore concentrated on avoiding instabilities that would lead to ring blow-up and particle losses. This may be achieved by an exact symmetry of the magnetic field and by faster crossing of all magnetic field regions where instabilities could grow up. The compression in the Garching electron ring experiment \(^1\) was therefore chosen one or two orders of magnitude faster than that in the experiments at Berkeley \(^2\), Dubna \(^3\) and Karlsruhe \(^4\). Nevertheless Faraday cup measurements (Fig. 1) as well as the analysis of X-rays emitted from thin adjustable obstacles seemed to indicate a relatively large radial extent during compression.

As even a thin obstacle (and a Faraday cup more so) probably strongly disturbs the ring, independent diagnostic methods were used for determining the total electron number, the electron density distribution and the energy in the compressed state. The results of these measurements are discussed.

Apparatus
The electron beam is produced by a Febetron-705 emission gun at an initial mean electron energy of 1.9 MeV. The instantaneous energy spread was measured to be more than \(\pm 2\%\). The electron current injected through the snout with a diameter of 13 mm was only about 40 A. The injection radius is 20 cm. The compressor consists of 3 nested coil pairs made of single copper rings which are fired in such a sequence that resonances should be avoided. The compression time is only about 10 \(\mu\)sec. The inflection of the electrons is performed by a magnetic inflector with a spread angle of 180\(^\circ\) and center position at 135\(^\circ\).

Measurements and Results
Magnetic probe and synchrotron radiation measurements were used as diagnostic methods. The total particle numbers obtained from Faraday cup measurements were compared with values from magnetic probe measurements of the proper magnetic field of the ring. Relatively good agreement was found.

At maximum compression of the electron ring, time, space and spectrally resolved synchrotron radiation was observed quantitatively. This diagnostic method does not disturb the ring at all and gives information about the density distribution and the energy of the electrons in the compressed state. The measurements in the visible region were done with photomultipliers and interference filters, simultaneously with those in the infrared region using InAs photodiodes and filters. The relative intensity distributions in the axial direction are given in Fig. 2, for the visible (and near infrared) region (top) and for 2.2 \(\mu\)m (bottom).

Both profiles (and also that in the radial direction, about 2 mm radius) are smaller than the radial ring extent obtained from the Faraday cup measurements. The profile at 2.2 \(\mu\)m is more extended than at shorter wavelengths.

The radiation is calibrated absolutely with the aid of a tungsten ribbon lamp. Fig. 3 shows the absolute spectral intensity of the synchrotron radiation from the visible region up to 3 \(\mu\)m in the infrared region at maximum compression at 3 cm. The points best fit the theoretical curve for 12.6 MeV. The curves are calculated with Schwinger's \(^5\) formulas.

This rough energy estimate is in very good agreement with the energy value derived from magnetic field measurement at the closed orbit radius of 3 cm. The measured magnetic field was \(B_\circ = 14.6\) kG at \(R = 3\) cm, which corresponds to \(E = 12.6\) MeV electron energy.

The total electron number can be found from the absolute intensity in the infrared region by integrating over the emitting volume and solid angle. A first rough estimate gives \(N_e = (8 \pm 3) \times 10^{10}\) electrons. Comparison with the value of \(12 \times 10^{10}\) electrons found with the Faraday cup probably indicates that most of the electrons are concentrated in the narrow density profile.

Discussion
The axial synchrotron intensity profile in the visible spectral region was found to be almost as narrow as it would be after ideal adiabatic compression. As the intensity in the visible spectral region is strongly dependent on the electron energy, the experiments indicate a narrow core of high energy electrons in the ring, and a more extended density distribution of electrons with lower energies.

As the incoming beam has instantaneous energy spread, even lower energy electrons can be inflected, as can be seen from Fig. 4, where electron orbits in the actual Garching compressor field are calculated for different initial energies \(^6\). The more the energy differs from the maximum inflectable energy, the larger are the radial betatron oscillations.

These large radial betatron oscillations cause a large axial spread by nonlinear coupling, as can be seen from three-dimensional orbit calculations in Fig. 5, where the projection into the \(R - z\) plane of
the electron orbits (with inflectors fired) is plotted for different initial energies.

Conclusion

A relatively narrow axial synchrotron intensity profile is found in the visible region, indicating nearly adiabatic compression of the high energy electrons. Thus, no effects of instabilities could be observed. The electrons with slightly lower energy are also inflected with larger radial and axial oscillation amplitudes, leading to a more extended infrared profile and also a profile such as measured with Faraday cups. At the present stage, however, the total particle number is too small compared with values suitable for collective ion acceleration. The main attention of the Garching group is thus being concentrated on increasing the phase-space density of the injected beam.

References

Fig. 5. Projection in R-z plane of the electron orbits (with inflectors fired) for different energies.

Fig. 4. Electron orbits in compressor midplane with inflection for different initial energies.

Fig. 5. Projection in R-z plane of the electron orbits (with inflectors fired) for different energies.