DEVELOPMENT OF HIGH CURRENT ELECTRON SOURCES FOR AN ELECTRON RING ACCELERATOR

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Abstract

This paper describes two ways to improve the Febetron 705 gun for ERA purposes: an open field emission tube with a graded acceleration system and a tube with a laser irradiated cathode. Compared with the normal Febetron tube, the ratio of useful to total current was improved by a factor of 10, the instantaneous energy spread was reduced from 5 % to 2.4 % and 1.1 % respectively (FWHM). Currents in an acceptance of 0.175 radcm are about 300 - 400 A.

1. Introduction

In the Garching ERA experiment we apply a field emission gun of the Febetron type 705 for electron injection, which only yields about 100 A useful current [1]. A further disadvantage is the very limited lifetime of commercial electron tubes (type 545 E, 500 pulses). Furthermore, a strong magnetic field is necessary to avoid electron bombardment of the tube wall, leading to unwanted angular momentum of the electrons in the beam.

The aim of our development is a useful current of 500 A from a tube where no magnetic field, but focussing by suitable electrical fields has to be applied. Large area field emission cathodes promise a long lifetime according to results at the LRL, Berkeley. We are therefore building our cathodes on this principle.

Parallel to the field emission tube we developed a version where the electrons are liberated by focussing a strong pulsed laser beam on the cathode.

To overcome the trouble with voltage breakdown along the inner tube wall we built multistage tubes with intermediate electrodes. The potential of these is determined by a resistive load consisting of a copper sulfate solution concentric to the tube axis. This load has several advantages:

> It divides the tube voltage uniformly, thus raising the electrical strength of the tube.
>
> It determines the potential of the intermediate electrodes, which are specially shaped to control the potential distribution in the acceleration system.
>
> It allows us to reduce the total electron current without mismatching of the pulse generator. So the space charge is reduced and the beam brightness is probably higher. Furthermore, the X-radiation is reduced.

2. Computation of the acceleration system [2]

2.1 Field emission tube

To get an electron beam of high quality which can be accelerated without additional external magnetic focussing, the position and shape of the accelerating electrodes inside the tube was calculated by analytic continuation of the potential from a self-consistent beam configuration with low spherical aberration.

This was done for a rotational symmetric structure which contains a plane field emission cathode. The finite beam emittance at the cathode was neglected. A highly transparent plane accelerating grid at an intermediate potential is assumed at a small distance from the cathode to achieve the necessary high and constant field gradient and a corresponding constant emission current density over the whole emitting surface. The anode aperture is assumed to be covered by a similar plane grid to avoid excessive defocussing and spherical aberrations at this place.

Between the cathode and the first grid plane the potential inside the beam is assumed to be radially constant in order to allow constant current density. This results in a Pierce-like shape of the electrodes outside the beam in this section. Between the first and second grids a radially slightly increasing potential distribution compensates the final radial momentum of the electrons in the beam approximately to zero. The beam shape and potential distribution in both sections were calculated by integrating a system of simultaneous differential equations. This system was obtained from the relativistic paraxial beam equation, taking into account space charge and magnetic self-constriction.

A result obtained by analytic continuation of the equipotential lines into the space-charge-free region is shown in Fig. 1 (thin lines). The calculation becomes unstable for larger radii.

2.2 Laser irradiated tube

For the laser-irradiated tube the above described computation could not be used since the beam is uncontrollably neutralized by positive space charges, especially near the cathode. An electrode system was therefore used which is slightly defocussing near the cathode and focussing in the other parts of the tube. To get the desired voltage gradient of about 50 kV/cm at the cathode and to meet the geometrical restrictions imposed by the laser beam optics, a four-electrode system (see Fig. 3) was used, the electrodes being equipotential surfaces of the potential function

$$V = A \sinh(Bz) . J_0(B\rho) + C$$

3. Experimental results with the field emission tube

We built a field emission tube as shown in Fig. 1. Four intermediate electrodes, separated by araldite rings, determine the potential distribution. The inner surface of the araldite rings is rippled to avoid flashover.

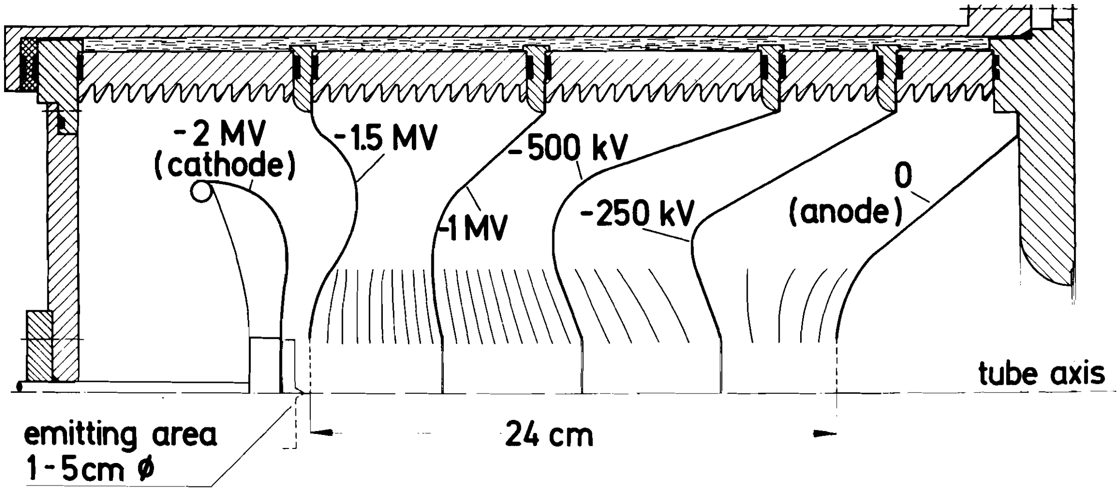

Fig. 1 Windowless field emission tube. The thin lines are the calculated potential lines.

The applied cathode with 2 cm diameter is composed of razor blades. The distance of the edges is 60 µm, and the radius of the curvature is 0.4 µm. The distance to the first intermediate electrode is variable. With 1 cm distance we got an emission current of about 1000 A at a total voltage of 2 MV. A magnetic lens focussed the beam in a system of two apertures with an acceptance of 0.175 radcm. The maximum current in this acceptance was 400 A (Fig. 2). The reproducibility was within 5 %. The half-width of the current pulse was 6 ns.

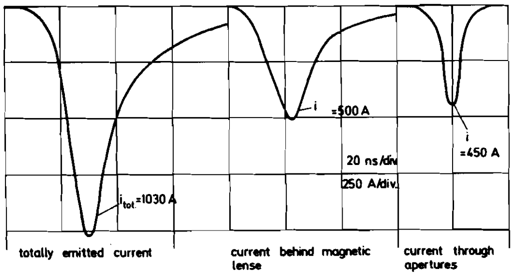

Fig. 2 Current pulse from the windowless field emission tube.

The time resolved energy distribution of the beam was determined with a magnetic analyzer (see Fig. 3). The result is an instantaneous energy spread of (2.4 ± 0.2) % (FWHM) at the moment of maximum energy (t_{max}), compared with 5 % with commercial tubes. The maximum of the energy distribution function at $t = t_{max}$ fluctuated 0.15 % rms from pulse to pulse, which is much less than the instantaneous spread in a single pulse.

The electron energy 2 ns before and after t_{max} is (0.7 ± 0.1) % lower than the maximum energy. The voltage signal gave a difference of 0.9 % for $t = t_{max} \mp 2$ ns.

The time interval important for beam inflection into our compressor is 8 ns. According to the data given above, a total change of the mean energy of about 3 % has to be expected during that time, this value being slightly larger than the instantaneous spread.

4. Experimental results with the laser irradiated electron tube

The structure of the laser irradiated tube is shown in Fig. 3.

The experimental results with this tube in the Febetron are: The emitted current depended on the laser power and the timing between the laser and voltage pulses. There were two regions for good emission, very short time delay of the voltage pulse, a few tens of nanoseconds, or delays of 1 - 2 μs. With short delay times the emission was sensitive to the jitter in time and amplitude of the laser pulse. With a delay of 1 - 2 μs we got good reproducibility of the current pulses. Furthermore, the energy output of the laser could be reduced to get currents comparable with the case with short delay times. **Figure 4 gives the dependence of the total current on the delay time.**

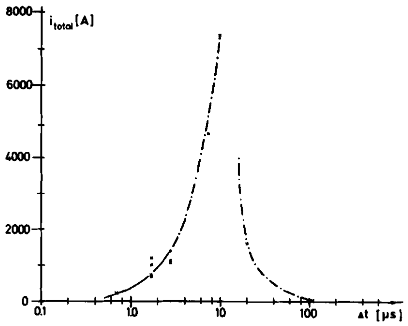

Fig. 4 Current dependence on time delay between laser and voltage pulses.

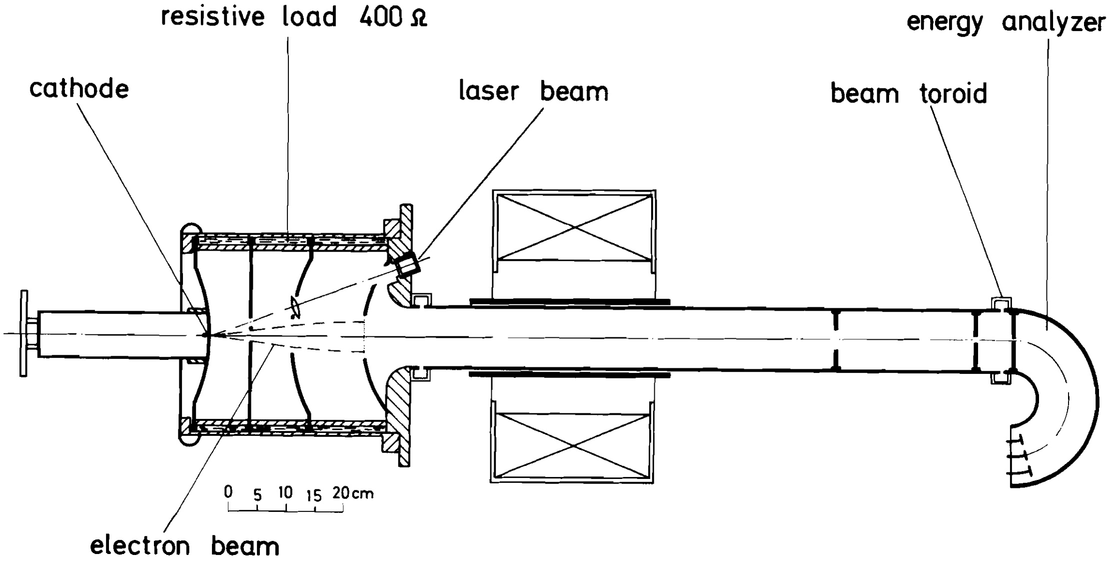

Fig. 3 Laser irradiated electron tube, together with aperture system and magnetic spectrometer.

There was a region where the current increased with increasing delay time, but then the generator was mismatched and the tube voltage decreased. At a total current of about 600 A we got a useful current of about 300 A in the acceptance of 0.175 radcm. The half-width of the current pulse was 17 ns and the instantaneous energy spread was 1.1 % (FWHM). In Fig. 5 the energy spread of the tubes involved are compared.

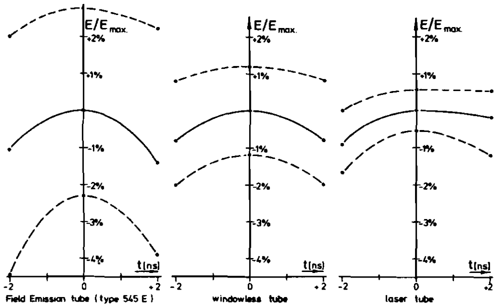

Fig. 5 Comparison of the instantaneous energy spread of the Field Emission tube (type 545 E), the windowless tube and the laser irradiated tube.

With both types of tubes the ratio of useful current to total current was improved by a factor of about 10. The instantaneous energy spread was reduced by a factor of 2 and 4 respectively. The lifetime of the tubes is not limited by vacuum or window breakdown and no magnetic field is necessary in the cathode region. Table I gives a comparison between the tubes used. We are continuing this work in both directions. Furthermore, a Blumlein circuit will be developed to get a better voltage source.

	i_{total} [A]	$i_{0.175\ rad\,cm}$ [A]	[%] inst. energy spread
commercial tube (type 545E)	4000	150	5.0
open tube (cathode diam. 20 mm)	1000	400	2.4
laser tube (Δt = 1.6 μs)	600	300	1.1

References

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