BEAM MEASUREMENTS ON THE ELECTRON INJECTOR FOR A HIGH CURRENT BETATRON*

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Abstract

The beam from a pulsed electron source for injection into a high current betatron has been investigated. Only cold cathode field enhanced emitters were considered. Carbon fiber bundles and hydrocarbon felt were tried in a gridded Pierce-geometry gun. The observed emittance was not acceptable at a current of 140 A and a diode potential of about 280 kV. An alternative source was investigated consisting of a single needle point cathode and a plane anode grid. At a current of 200 A an emittance of $\epsilon = 44\pi$ cm mrad was observed. The spherical aberration of the source was found negligible. The pulse length of the high voltage pulse was about 20 nsec. The turn-on delay times for the carbon fiber and the needle point cathode were around 10 to 15 nsec.

Introduction

Design and construction of a high current betatron [1] was started in the summer of 1984 at the Institute for Accelerator and Plasma Beam Technology of the University of New Mexico. An electron beam current of 100 A from a 300 kV electron gun will be injected by a pulsed electrostatic inflector into a betatron with 8.28 m circumference. The betatron will have a race-track geometry with injection along the straight section. The betatron will have two accelerating gaps isolated from each other by ferromagnetic pulse isolation cores. Focussing is done by alternating solenoidal fields. The guiding magnetic field is generated by coreless field coils which will track the energy of the electrons to maintain the betatron condition.

Beam measurements on the injector are described in this paper.

Experimental arrangement

The power driving the electron source is provided by a 1 kJ, 300 kV Marx generator. It is composed of 6 storage capacitors and three gas switches. One of the switches is triggered. The rise time of the high voltage is about 15 to 20 nsec. The output of the Marx generator is connected over a damping resistor of 12.5 Ω to the cathode of the electron gun. Parallel to the gun is an inductive load to ground with saturating ferrite cores. After the cores saturate the voltage at the diode is loaded down to a small fraction of the high voltage and damped by the series resistor. This results at the present in a high voltage pulse at the diode of about 280 kV and a pulse length of about 20 nsec FWHM. The pulse duration will be increased in the future by additional ferrite cores to yield a flat top.

Different electron sources were mounted in a vacuum manifold at the Marx generator oil tank. That structure also held an integrating Rogowski coil for beam current measurement and two focussing solenoids which match the source beam to a straight transport tube.

The 100 cm long beam transport tube with an inner diameter of 3.8 cm and alternating magnetic solenoid focussing was attached and preliminary tests with the electron beam were performed.

Beam measurements on the electron source

Two source geometries were investigated and different cathode structures tried. The original source had a Pierce geometry and was designed for an electron current of 200 A at a diode potential of 300 kV. The beam diameter was 3.2 cm and the corresponding cathode/anode distance was 4 cm. The cathode consisted of carbon fiber bundles [2] arranged in a rectangular 7 by 7 mm array. The anode consisted of a stainless steel mesh with a mesh width of 20 mil and a transmission of 81%.

Beam measurements on this diode gave an electron current of about 140 A at a diode potential around 280 kV. One would expect an electron current beyond the anode of about 146 A. Current measurements were done with an integrating Rogowski coil at the diode output.

The measurement of beam geometry was done with a pinhole arrangement followed by a fluorescent screen typically 2 cm downstream. The image on the fluorescent screen was then recorded with an open shutter camera on a 3000 ASA speed Polaroid film. The time integrated exposure on the positive was analysed by a reflecting densitometer (fig. 1).

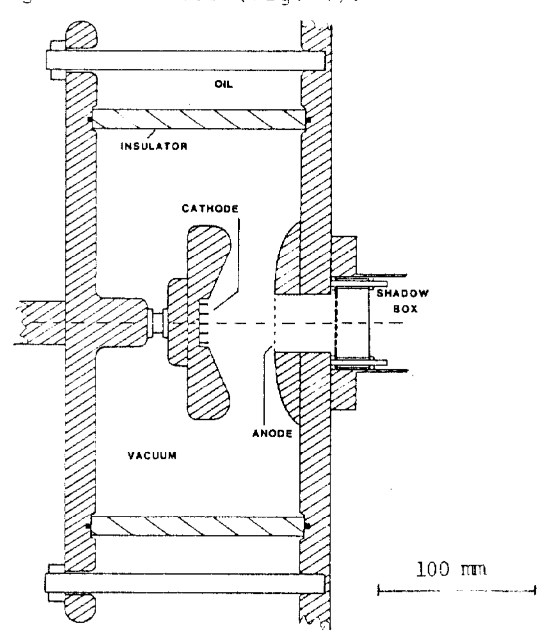

Fig. 1. Schematic of the Pierce gun with carbon fiber bundle cathode and the shadow box diagnostic.

The beam geometry measurements indicated a beam with a rather large intrinsic divergence. Essentially all fiber bundles contribute to the beam at any beam position. Only the width of the anode aperture and the cathode diameter limit the intrinsic divergence of the beam. This is documented by the shadowgraph where each pinhole produces an image of nearly the whole cathode (fig. 2). The emittance was around $\epsilon = 200\pi$ cm mrad and too large for injection into the betatron even if the beam current were truncated to 100 A.

Reducing the distance between fiber bundles to a 5 by 5 mm array did not improve the emittance.

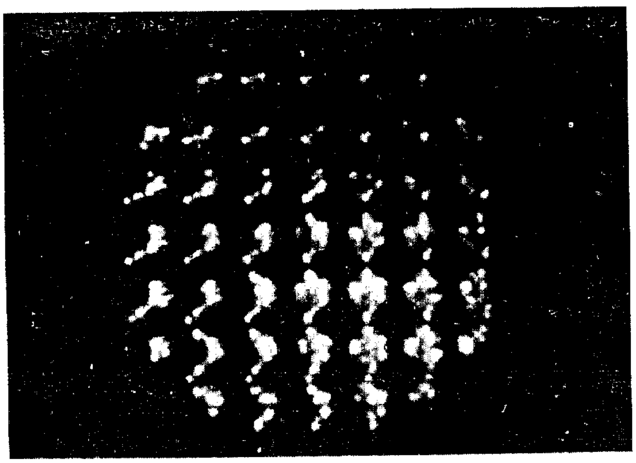

Fig. 2. Shadowgraph of the beam using a fiber bundle cathode in the Pierce gun.

Next a cloth hydrocarbon fiber cathode [3] was used. It gave very non-uniform emission. The divergence was only slightly reduced.

In a further attempt to reduce the emittance, the carbon fiber bundles were removed except for a central one. The measured current was reduced to about 80 A. The divergence from the bundle itself was not changed but the emittance was reduced by having a smaller emitting area on the cathode. The carbon fiber bundles had the tendency to spread out after repeated use. The turn-on delay was about 10 to 15 nsec.

Keeping the notion of a smaller emitting area at the cathode, a steel needle was used as a cathode and the gap was reduced to get a large enough current. The anode was still a plane grid with a transmission of 81%. The distance between needle point and anode grid was typically 1 cm (fig. 3). The observed electron current was around 200 A and strongly dependent of the distance between needle tip and anode mesh. The electron beam current turned on within 10 to 15 nsec (fig.4). The beam was divergent but the intrinsic divergence was significantly reduced compared to results from the extended cathodes (fig. 5). Quantitative evaluation of the photo emulsion with a reflecting densitometer gave an emittance of $\epsilon = 44\pi$ cm mrad including 50% of the beam current (fig. 6). The corresponding brightness for a total beam current of 200 A was $B = 5.3$ kA cm^{-2} rad^{-2}. The normalized values were $\epsilon_n = 57\pi$ cm mrad and $B_n = 3.1$ kA cm^{-2} rad^{-2}.

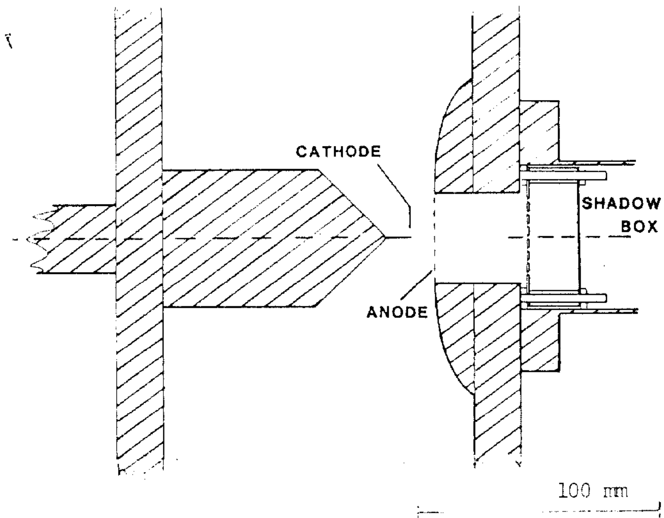

Fig. 3. Schematic of the electron source using a steel needle as a cathode.

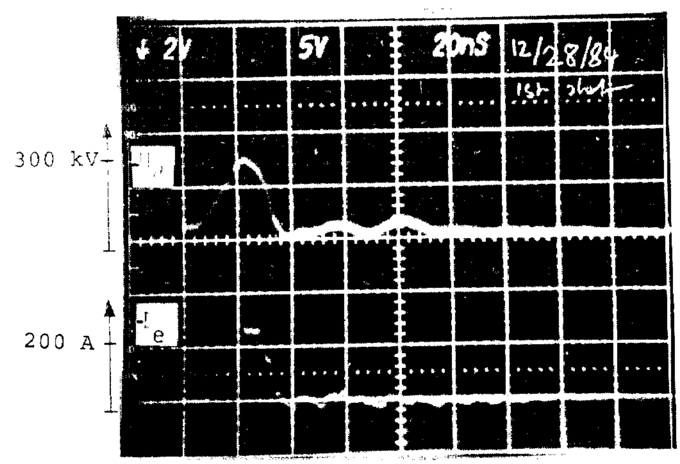

Fig. 4. Voltage and electron beam current from the needle cathode source.

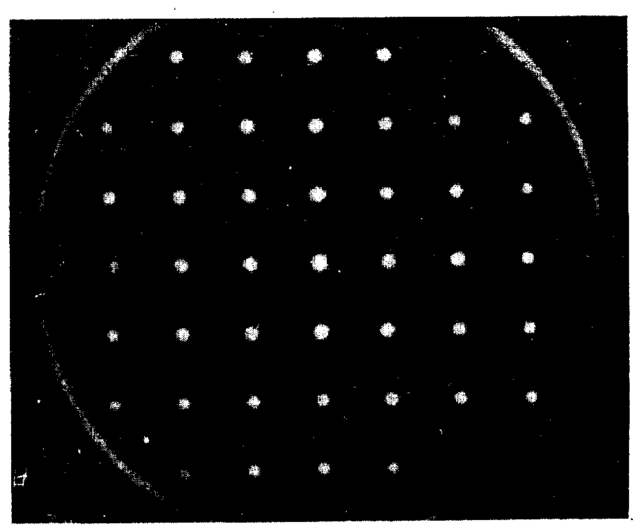

Fig. 5. Shadowgraph produced by the beam from the needle cathode gun.

If one tries to describe the electron current by spherical space-charge-limited flow [4] then one would expect for a gap of 1 cm and a solid angle of 0.38 sr an electron current of less than about 50 A beyond the anode grid. The experimentally observed current of 200 A could be achieved theoretically by an increased effective needle tip radius of about 0.3 to 0.4 cm. This increase of the effective cathode radius could come about by an expanding plasma cloud. In that case the plasma would have to expand with a velocity of at least 15 cm/μsec. Measurements at larger distance between needle and anode grid indicate that most of the gap reduction is due to the expansion of the cathode plasma. The spherical aberration was small compared to the intrinsic divergence.

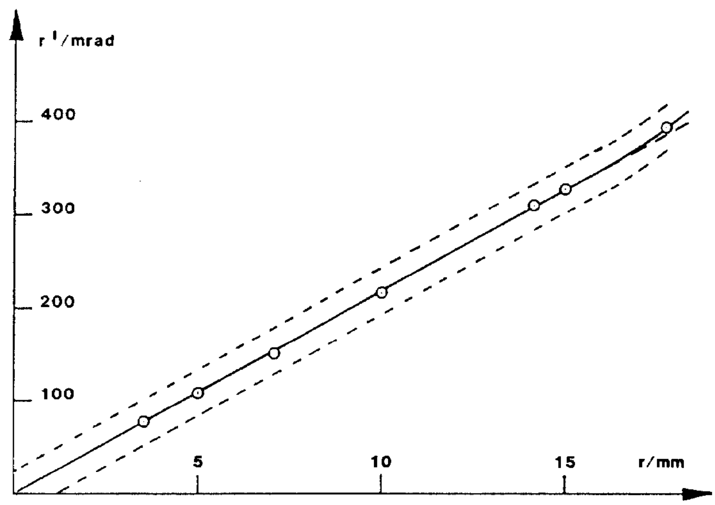

Fig. 6. Emittance area of the electron beam from the needle cathode source 3.7 cm downstream of the anode grid. The area contains 50% of the beam.

Conclusion

The beam from a simple electron source has been investigated. The source cathode consisted of a steel needle typically separated 1 cm from a plane anode grid. It worked as a field enhanced cold electron emitter. At a diode potential of about 280 kV and an extracted electron current of 200 A an emittance of $\epsilon = 44\pi$ cm mrad was measured for 50% of the beam. The spherical aberration could be neglected. The emittance was significantly smaller than for other extended cathodes at similar current levels.

The reproducibility of the beam current has to be investigated further, especially with longer pulse duration.

References

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