PRELIMINARY EXPERIMENTS WITH A CARBON FIBER TUFT CATHODE

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ABSTRACT

This work reports initial tests of a carbon brush or tuft cathode intended for use by the Beam Research Program. It was found that electric fields of approximately 100 kV/cm were required to produce current densities above 20 A/sq cm. The beam extracted from the cathode consisted of many beamlets -- one for each tuft. The beamlets were found to be quite uniform in peak current density and the cathode operation was microscopically repeatable. The turn-on time was estimated to be 200 ns.

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1. Introduction

On Monday, December 19, 1983, a series of experiments were performed with a field emission cathode that consists of a number of carbon tufts. A drawing of the cathode is contained in Fig. 1. The tufts were formed by weaving a length of carbon yarn through holes drilled in a stainless steel plate and then cutting the yarn to form tufts of length equal to the spacing between holes. The spacing between holes was 0.25 inches (0.64 cm) and the area of the cathode is approximately 53 square centimeters. The area of this cathode is slightly greater than one tenth that of the ATA and ETA cathodes.

The carbon fiber or tuft cathode was originally developed by R. Prohaska and A. Fisher of U. C. Irvine (1). They report cathodes made of felt and yarn that operate at current densities of 1-10 A/cm sq. with total currents of several kA for periods of 10-100 μ s. Potentials of 5-15 kV and fields of 10-30 kV/cm are used.

A tuft or carbon fiber cathode is in use in the FEL experiments in progress at the Naval Research Laboratory under John Pasour (2). At NRL the cathode is used as the source of electrons for a beam of 0.8 kA for up to 2 μ s. The gun used for these experiments is an Astron accelerator gun that was given to James Leiss at the National Bureau of Standards in 1971 or 1972. It was transferred to NRL at the completion of the NBS tests about 1980. The cathode area of this gun is approximately one-half the area of the ATA/ETA cathodes.

A study of cathodes for microsecond beams is reported by Ramirez and Cook (3). They report experiments performed on five different cathodes: a 30.3 cm long 0.003 cm thick titanium blade clamped in an aluminum holder; a metal oxide matrix cathode consisting of < 1 μ m dia. tungsten fibers at

surface densities near 4 million per sq. cm.; a carbon fiber or tuft cathode similar to that reported here. A flashover board cathode; and a plasma cathode in the form developed by Loda (4) as originally used on ETA. They conclude that the carbon fiber or tuft cathode gives a non-uniform and non-repeatable beam. The metal oxide field emitter turned on slowly, required a large electric field, and proved to be quite fragile. The two plasma cathodes showed more rapid closure velocities and could not be controlled if the cathode-anode gap were allowed to fill with plasma before the current was extracted.

II. The Experiment

Experiments were performed in the test stand put together by Birx et al. The test stand consists of an ATA cell driven by a magnetic pulser. The pulser is able to supply voltage pulses up to 300 kV with a pulse width of 70 ns. The pulse is limited by the amount of ferrite in the ATA cell. The experimental procedure was similar to that used by Birx in his recent tests (5) of the ATA/ETA plasma cathodes.

The cathode was mounted so that the plane of the carbon tufts was the same as that of the surrounding metal. The anode-cathode gap was 2.6 cm. The anode was a titanium plate approximately 0.25 in. thick. Holes 0.050 inches in diameter were uniformly drilled on 0.2 inch centers through the anode. Electrons that found their way through the holes in the anode passed through a drift space and struck a fluorescent target placed at an angle of 45 degrees to the system axis. The light generated by the electrons striking the phosphor

was viewed by a gated TV and recorded on a video tape recorder. The phosphor has a response time of 0.4 to 0.6 ns. The TV gate was set at 10 ns.

The beam was transported and focused from the cathode to the phosphor by the magnetic field produced by a single coil placed just beyond the anode as shown in Fig. 2. The field produced by this coil is quite non-uniform as shown in the field and mod-B plots presented in Figs. 3 and 4. These calculations indicate that the field at the anode is approximately 7 Gauss/Amp and the field at the cathode is less than 5 Gauss/Amp. The field increases to nearly 40 Gauss/Amp under the coil and then decreases to 12 Gauss/Amp at the center of the phosphor. The lines shown in Fig. 5 are the projection of the phosphor plane in the mod-B surfaces. Thus the field varies from about 40 Gauss/Amp to 7 Gauss/Amp within 5 cm of the system axis on the plane defined by the phosphor.

During the experiments the voltage applied to the anode was varied from 0 to 280 kV. The focus coil current was varied from 0 to just over 7 Amps. A cathode life test consisting of approximately 30,000 pulses was performed.

III. Results and Analysis

Typical waveforms observed in these tests are presented in Fig. 5. It was found that the current was a sensitive function of the anode voltage and that it could be varied from 40 Amps to 1.3 kA within the parameters of the magnetic pulser. At peak parameters at one Hertz the radiation near the quartz window was 10 to 30 mR/h. The current-voltage characteristics of the cathode are presented in Fig. 6. These same data are plotted in Fig. 7 as

current density versus electric field and compared with the value expected from the Child-Langmuir equation. Figure 8 contains the current density normalized to the Child-Langmuir value. The currents and voltages used for these graphs were the maximums observed on the oscilloscope. The current through the focus coil had no influence on these data.

If the focus coil was energized, the pattern observed by the gated TV and recorded by the video tape recorder consisted of from 9 to 16 clearly distinguishable spots or blotches. A copy of the spot pattern observed by the TV is poorly reproduced in Fig. 9. At beam currents near 1 kA the spots were sharp at a coil current of 7 amps. At currents of 0.1 kA the spots were sharp at a coil current of 5.5 amps. After considerable experimentation and consternation it was determined that the spots were produced by an alignment of the cathode tufts with the anode holes. The alignment occurs on exactly one inch centers because the tufts are 4/inch and the holes are 5/inch. A rotation of the cathode by 45 degrees with respect to the anode completely eliminated the spots. Numerous other tests involving blocking the anode holes with metal tape confirmed this interpretation.

An estimate of the turn-on time of the cathode was made by assuming that under all conditions the cathode current was approaching the space charge limited (C-L) according to:

$$J = J_c - 1(1 - \exp(-t/T)).$$

Here $J_c - 1$ is the Child-Langmuir value, t is time and T is the cathode turn-on time. Values of T were found by determining the rate of change of current density at the time the voltage pulse appeared flat from the oscillograms contained in Fig. 5. These estimates are contained in Fig. 10 which suggest a

turn-on time of approximately 200 ns at an electric field of 100 kV/cm. This procedure is quite subject to error. As a consequence the data of Fig. 10 should be questioned and preferably repeated in a followup experiment.

The pictures recorded by the video tape recorder were digitized and analyzed by the computerized TV image processing system. These pictures showed that at mean current densities near 20 A/sq cm the peak current densities of typically 6 of the 16 beamlets observed in the images were within 12%. Nine of the beamlets were uniform to within 40%. Moreover, even on a microscopic scale the beam pattern was very repeatable on a shot-to-shot basis. In this respect the beam produced by this cathode is considerably better than that produced by the ETA/ATA plasma cathode as documented in the experiments by Birx (3). Due to the interactions of the beamlets produced by the cathode tufts with the holes in the anode it is not possible to obtain an accurate estimate of the uniformity of the beam generated by this tuft cathode.

During the course of the cathode life tests the beam current was observed to drift both up and down over a long (tens of minutes) time scale. This long term drift is documented in the oscillograms of Fig. 5. In approximately 1.5 hours the beam current dropped from 1.2 kA to 0.9 kA. In a later life test at 20 Hertz the beam current was observed to decrease and then increase to more than the original value. The cause of this phenomena is not known.

IV. Comments and Conclusions

Table 1 contains a list of the parameters of this experiment and of those of the experiment of Ramirez and Cook (3).

Table 1

	R/C	TJF
Cathode Area	420 cm sq	53 sq cm
Tuft Spacing	1.25 cm	0.62 cm
Tuft Length	1.00 cm	0.62 cm
A-K Spacing	9.3 cm	2.6 cm
A-K Voltage	180 kV	300 kV
Electric Field	20 kV/cm	100 kV/cm
Pulse Width	1.2 μ s	70 ns
Beam Current	3.0 kA	1.0 kA

A comparison of parameter in this experiment and in that of Ramirez and Cook (3)

The results of these experiments are not as optimistic as predicted by the work of Ramirez and Cook (3). Their data indicate that at mean field values of 10 to 20 kV/cm one should expect Child-Langmuir current densities after 60 ns. They measure a gap closure velocity of about 1.5 cm/ μ s. On the basis of this determination they observe that the turn-on delay of 60 ns is consistent with the plasma expansion velocity and the tuft spacing. If this were the essential physics we would have observed a turn-on delay of less than 30 ns.

These experiments revealed that the hole pattern in the anode strongly affected the beam uniformity as recorded by the gated TV system. Since Bix used the same experimental apparatus one should suspect that his beam uniformity measurements may be overly pessimistic. The experiments on both the plasma and tuft cathodes should be repeated with a different anode structure. It should be possible to use a thin (1/8 inch) aluminum or titanium anode with the phosphor painted on the back side. Although this anode is range thick to the electron it should be sufficiently excited by the gamma rays to produce an image that can be observed by the gated TV. The "velum effect" insures that such an image will reveal the beam current density.

On the basis of this experiment a tuft cathode for ATA can be designed. This cathode will be able to provide 10 or more kamps of beam current. It will require a grid-cathode pulse of approximately 150 kV with a spacing of 1.5 cm. Since the ATA grid pulser will work better at 150 kV than where it is presently being operated the only changes to ATA involve an upgrade of the connectors to the ATA grid. This cathode should give a more uniform beam but the current pulse will not be square.

The hope of these tests was that the tuft cathode would emerge as a better electron source than the plasma cathode and that it could be used in ATA with no need for extensive and expensive modifications. This hope was at least partially realized. A 500 sq. cm tuft cathode will probably work in some fashion in ATA or ETA. Whether it will work better than the present plasma cathode is questionable. Further tests on a test stand are clearly indicated. Nonetheless, it is probably worth fabricating a tuft cathode for ATA in case future experiments clearly reveal that the plasma cathode is responsible for the ATA beam transport problems.

Acknowledgements

Several people contributed to this work. Dan Birx not only designed the test apparatus but also contributed to the design of the tuft cathode and the interpretation of the experiments. The data taking and experimentation was done by a variety of interested individuals who wandered through the test area and were pressed into experimental service. These included Dave Trimble, John Schmidt, Lou Reginato, and John Clark. The cathode was designed by Ted Yokota and fabricated by Cliff Holmes.

References

- (1) R. Prohaska and A. Fisher, "Field Emission Cathodes using Commercial Carbon Fibers," Rev. Sci. Instrum. 53(7), p. 1092, (1982).
- (2) John Pasour private communication.
- (3) J. J. Ramirez and D. L. Cook, "A Study of Low-Current-Density Microsecond Electron Beam Diodes," J. Appl. Phys. 51(9), p. 4602, (1980).
- (4) G. K. Loda, "Electron Gun for High Average Power VV/Visible Lasers-Final Report," Systems, Science and Software Report SSS-79-11400-FR, January 1979 (unpublished).
- (5) D. Birx, "Tests of the ATA Plasma Cathode," Talk given at the ATA Accelerator Workshop, December 12, 1983.

EXISTING COVER PLATE
 PLASMA CATHODE
 (DAN BIRX LWS.)

Figure 1

Figure 2

Figure 3

Figure 4

Brush Cathode Experiment

12/19/63.

Note: Low γ Count used to
Also observed at 100%
← 100% $\frac{1}{10}$

Figure 5

Figure 6

Figure 7

Figure 8

AT 24°

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Figure 9

Figure 10