© 1987 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

PRELIMINARY EXPERIMENT ON THE ELECTRON BEAM EXTRACTION FROM A STELLATRON

H. Ishizuka, A. Fisher, K. Kamada, R. Prohaska and N. Rostoker Physics Department University of California Irvine, California 92717

Abstract

The stellatron is a high current electron accelerator that employs a stellarator field in addition to the betatron field. A substantial fraction of l kA was accelerated to 10 Mev in a glass torus either lined with stainless steel mesh or coated with molybdenum. The same current and energy were observed with a torus made of graphite epoxy composite, to which an extraction port was attached. A Faraday cup placed in this port detected electrons, up to 1 μ C per pulse at beam energies of a few MeV, when a pulsed magnetic field was applied to expand the beam orbit.

Introduction

An experimental study of the stellatron has been pursued in the last three years. The goal (1 kA, 10 MeV) has been attained in regard to the electron current and energy but not simultaneously [1, 2]. The major issues to be addressed at this point are (1) suppression of beam decay and (2) extraction to facilitate emittance measurement and beam utilization in the absence of magnetic fields.

Method of Extraction

Problems

Several methods are applied to extract beams from conventional betatrons. The basic requirements for good extraction are (1) sufficient perturbation to permit electrons to jump out of the guiding field, (2) negligibly small influence on the beam before the extraction, and (3) focusing action. These are common to the stellatron case, while the field configuration and the beam dynamics are remarkably different. In the stellatron, electrons are much more reluctant to change their orbit. They do not move on planes. The stellarator field, which is stronger than the betatron field, increases toward the torus wall. Thus a new extraction scheme and/or modification of machine parameters are required.

Orbit Expansion

The closed orbit in a stellatron is a helix when there is mismatch between the electron momentum and the vertical field [3]. The beam center undergoes an oscillation around this closed orbit and electrons oscillate around the beam center. Let us consider a loop, indicated as the spiller in Fig. 1, that goes all the way around the major diameter of the torus. When a current is started in it to produce a field that opposes the betatron field, the closed orbit is driven outwards. The spiller field increases with radius, and the momentum compaction factor is greatly increased at a certain distance from the spiller winding. The beam orbit is expected to expand rapidly near this radial position.

Focusing

A drift space for extraction must be provided. A hollow conductor was used to screen the betatron and the helical fields. The toroidal field must extend into it to avoid electron deflection near the entrance.





The azimuthal mode number m of the stellarator field must be made as small as possible in order to reduce spirality of the orbit.

Experimental Procedure

The UCI stellatron has been operated at m = 12or 8. The first step in this work was to operate the machine at a smaller m. The orbit expansion due to the spiller field was next verified using a Faraday cup inserted into the torus. The effect of field perturbations, that were caused by introducing a conductor into the torus, on the beam confinement was also examined. The beam energy was checked by placing absorbers in front of the Faraday cup. Then a half section of the glass torus was replaced by a graphite torus. An extraction port was attached and electrons were detected in it. The spiller was operated when the beam energy reached a few MeV.

Experiment

Apparatus

The vacuum chamber was 41 cm and 4 cm in major and minor radii, respectively. Three sets of magnetic fields were applied: the betatron field, toroidal field and the helical field [1]. In this series of experiment, the peak toroidal and the betatron fields were limited to 10.5 kG and 540 G, respectively, to facilitate machine maintenance. The spiller field was generated by discharging a $0.1 - 0.8 \ \mu F$ capacitor bank through a triggered sparkgap. The operating voltage was $20 - 40 \ kV$.

Figure 2(a) shows a Faraday cup encased in a copper tube. The tube was typically 16 mm in outer diameter, 2.5 mm in wall thickness, and 40 mm in length. An aluminum filter (a disk used for electron absorption) covered the front end, while the rear end was shielded with copper. The Faraday cup was radially movable and also rotatable around a rigid coaxial cable. An extraction port attached to the graphite torus is illustrated in Fig. 2(b). A copper snout, 19 mm in outer diameter and 3 mm in wall thickness, stuck into the torus. It was slotted so that the toroidal magnetic field penetrated.



Fig. 2 - (a) Faraday cup inside the torus. (b) Extraction port.

General Features

Typical time sequence of operation and signals are shown in Fig. 3. A plasmoid was injected into the torus, from either the outer or inner side, with a small plasma gun [2]. The plasma was confined by the stellarator field and a runaway current started when the betatron field was applied. The current was terminated by activating the spiller. At the same time, the Faraday cup and X-ray PIN diodes presented signals which were as narrow as 100-300 ns. Dotted lines in the figure show the signals in the absence of the spiller field.



Fig. 3 - Typical time sequence of operation and signals.

Reduction of the Mode Number m

The helical windings were supported by G-10 rings that fitted into the toroidal field coils. The pitch of the windings was constant within the rings but adjusted between the toroidal field coils to alter m. As a result, the windings deviated materially from pure helices for low values of m. Such a distortion has, however, little effect on the rotational transform angle [4]. As m was changed from 12 to 8, 6 and 4, the helical current necessary to observe the beam decreased. This critical current and the rotational transform angle are shown in Fig. 4. The beam current was insensitive to m, while the X-ray pin-hole



Fig. 4 - Critical helical current and rotational transform angle

pictures indicated that the axial pitch of the electron beam became longer with decreasing m as expected.

Faraday Cup Inside the Torus

The beam was not affected significantly if the far side of the copper tube stayed within approximately 1 cm from the outer wall of the torus. As it was moved inwards, the beam current decreased and the decay became quicker. The Faraday cup showed a signal when the spiller field was applied. The signal was largest when the Faraday cup was near and parallel to a helical wire which carried a current such that it repelled the beam. The peak reached 2 A and the half width was typically 100 ns. If the front disk was removed and the Faraday cup was rotated by 180 degrees, an ion signal appeared which was smaller than the said electron signal by two orders of magnitude. X-ray pinhole pictures showed that most of the beam electrons hit the copper tube.

The electron energy was evaluated by the absorption method changing the thickness of the aluminum disk. In Fig. 5 are plotted Faraday cup signals for three values of disk thickness against the time when the spiller field was applied. The solid lines are theoretical curves based on the electron transmission factor through slabs [5] and the betatron acceleration. The electron energy calculated from the betatron acceleration is also shown on the horizontal axis.

Removal out of the Torus

The beam current and the beam's behavior remained unchanged when replacing a half of the glass torus with a graphite torus. The snout was inserted within a limit not to disturb the beam, and the Faraday was placed so that its innermost edge stayed



Fig. 5 - Electron transmission through aluminum disks.

inside the torus wall. A signal was obtained by applying the spiller field, as shown in Fig. 6, if the



Fig. 6 - Electron removal into the extraction port

helical current nearest to the extraction port was in such a direction as to repel the beam. The signal was not affected by biasing the Faraday cup within \pm 2 kV..

The collector current increased by a factor of 7 when m was reduced from 6 to 4. It increased with the operating voltage of the spiller. The peak signal and the collected charge reached 8 A and 1 μ C, respectively. The signal started to rise when the spiller current was approximately 600 A and reached the peak at 1.6 - 2.4 kA. X-ray pin-hole pictures showed that most of the beam electrons hit the snout along the helical winding. If the Faraday cup was removed and the extraction port was vacuum-sealed at its end, electrons ejected into the air were observed visually with a plastic scintillator.

Discussion

We have observed for the first time extraction across the guiding fields in a stellatron. The beam orbit expands due to the spiller field and forms a helix corresponding to a theoretical closed orbit. About 10% of the beam enters a field excluding snout and is collected on an 11 mm diam Faraday cup. The rest of the beam hits the snout under the present conditions. The absorption data taken suggest that the electron energy is consistent with the betatron acceleration. For sake of comparison, we may observe that among conventional betatrons extraction efficiencies vary from 10% to 70% [6]. Azimuthally local field perturbations (coils or extraction snout) have little effect on stellatron performance. Another important finding is that the beam parameters are insensitive to the mode number m of the helical field. m will be reduced below 4 and the spiller will be operated at higher voltages in future to improve the extraction efficiency.

This work was supported by the Office of Naval Research.

References

- H. Ishizuka et al, "Injection and Capture of Electrons in the UCI Stellatron,"<u>Trans. Nucl.</u> <u>Sci.</u>, Vol. NS-32, No. 5, pp. 2727-2729, 1985.
- [2] H. Ishizuka et al, "Beam Acceleration in the UCI Stellatron," in 6th Int. Conf. on High-Power Particle Beams, 1986 (to be published).
- [3] C. W. Roberson, M. Mondelli and D. Chernin, "The Stellatron Accelerator," <u>Particle Accelerators</u>, Vol. 17, pp. 79-107, 1985.
- [4] I. S. Danilkin, "Effect of Geometric Errors in the Magnetic System on the Field Configuration in a Stellarator," in Proc. of P. N. Lebedev Physics Institute, Vol. 65, 1979, pp. 23-45.
- [5] C. D. Zerby and F. L. Keller, "Electron Transport Theory, Calculations, and Experiments," <u>Nucl. Sci.</u> <u>Eng.</u>, Vol. 27, pp. 190-218, 1967.
- [6] R. S. Foote and B. Petree, "A Pulsed Magnetic Extractor for Removing the Electron Beam from a Betatron," <u>Rev. Sci. Instr.</u>, Vol. 25, pp. 694-698, 1954.