Plan for the Ion Source Emittance Measurement Under the RF Extraction

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ABSTRACT

An experiment is planned to measure the emittance of a cyclotron ion source under rf extraction and in magnetic field up to 8 Tesla. Preparing for that, computations have been done to choose the slit locations and the shape of the extraction electrode. Computer simulation of many particles produces current distributions for various slit positions, which can be compared with experimental results. The sensitivity of the experiment may not be sharp due to tight requirements(8 Tesla, D^+, 50kV rf), but a careful experiment will apparently measure emittance as a function of rf time.

1. INTRODUCTION

Initial conditions of ions from the internal source in the cyclotron needed for computer studies of orbits have usually come from emittance measurements under dc extraction; possible effects of the oscillating radio frequency extraction voltage on the source emittance have been neglected, which is likely to be a significant error. Using an appropriate slit system, it appears that rf phase can be selected within some degrees, and the emittance measured as a function of rf phase directly inside of the magnet after extraction by the rf electric field. This method requires orbit calculations to interpret the results since an emittance effect on the orbits must be separated from the spread by phase, and a special central region design with ion source and slits is needed to meet this purpose. Three slits are employed to separate the three coordinates, phase, and emittance, i.e., including one more slit than the usual two slit method.

Another way of measuring the rf phase dependence of the emittance would be to observe the time dependence of current as a function of rf time, but this would be difficult due to the rf noise picked up with the current signal which has the same frequency. A PIG source(cold cathode) shown at Fig. 1 similar to one being used at Harper cyclotron[1] will be built. Measurements will be made for different plasma conditions controlled by arc current, gas flow, etc., and magnetic fields up to 8 Tesla, which will be provided by the test magnet under construction.[2]

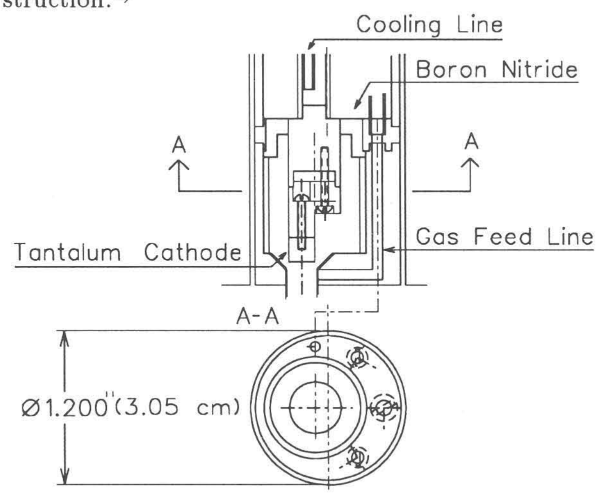

Fig. 1. PIG source designed to fit on the central hole of 8-Tesla magnet

2. CENTRAL REGION DESIGN AND CALCULATION RESULTS

The design of the central region for the emittance studies, including PIG source, puller, and ground plate, is done with an aim of spreading the beams having different rf starting time so that the emittance can be compared for different rf ranges selected by a phase slit. The general arrangement of central region electrodes in the test apparatus is shown in Fig. 2. The rf provides a two gap acceleration with a flight path of about 90° between the two gaps so that orbits with different initial phase are sharply spread. Three slits(S1,S2, and S3) approximately equally spaced, are located on the grounded dummy dee side of the system which allows easy control. The motions of slits are limited as the beam stopping area in slit touches the wall, so different slits with aperture close to the end have to be used for rf phase below 200°. The proposed extraction voltage of 50 kV

*Work supported by the U.S. National Science Foundation.

and peak electric field of 200 (kV/cm) at 5 - 8 Tesla magnetic fields come from previous experience[1] at 4.6 Tesla. For exploratory calculations initial total energy(E_t) and incident angle(α) from the PIG source as initial conditions of design calculation are inferred from dc emittance results.[3] Several such orbits are shown in Fig. 2 for different rf starting time using deuterons(D^+) as a test particle with 250 eV initial energy and 8 tesla flat magnetic field.

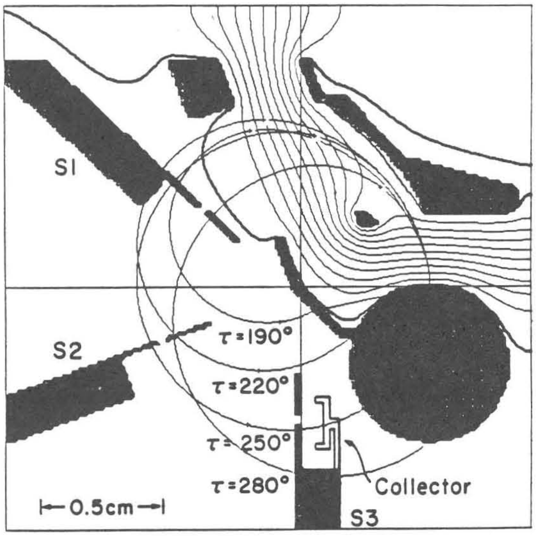

Fig. 2. The orbits on the schematic view are shown, calculated for 4 different rf phases (270° is peak voltage on the first gap). The initial energy of D^+ is 250 eV, and ions are started at the center of the source with zero divergence angle.

As we study the emittance, rather than a few particles, part I of CYCLONE program[4] is modified to handle many particles effectively and to include the slit actions. Since transmission will be measured in slit coordinate space, we need to compute the relationships between two spaces to obtain the emittance. The boundary of a rectangular shape in source phase space for different emittances described at Table 1 is projected into the slit coordinate space in Fig. 3. The spread by larger emittance appears to include smaller ones in a defined manner as the boundaries in two spaces are qualitatively related as shown in Fig. 4. The ions having different rf starting times go to fully separated regions in the slit space for starting time intervals differing by 10 degrees, i.e. rf time is well separated at slit S3. The resolution of the measurement depends on the area occupied by the beam in the slit space. In this sense the slit S2 has less orthogonality relative to S1 and S3 than might be desired. An increase in the S1, S2 spacing might be helpful and will be investigated. The actions of each slit are described, even though all three slits together select the rf phase space and the emittance coordinates.

Table 1. The initial conditions used for orbit calculations in figures 3,6, and 7. source opening size, and normalized emittances($\epsilon_o\beta\gamma$)(mm·mrad)

$E_t(eV)$	α	Opening	ϵ_n	Fig.3
250	±22°	0.381 mm	0.15	solid
250	±22°	0.762 mm	0.30	dash
250	±44°	0.762 mm	0.60	dot

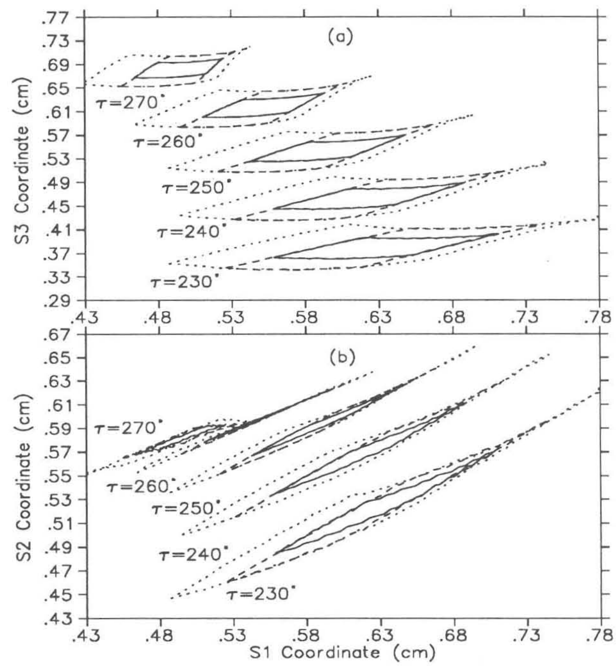

Fig. 3. The projection of the rectangular initial phase space into the slit coordinate space for five different rf starting time in the interval of 10 degrees. The dashed line is for a larger source width, and the dotted line is for an increased divergence angle, which are described in Table 1. The area occupied in the slit coordinate space shrinks for the same emittance as the rf starting time rises.

The slit S1 makes a cut angled in phase space because the rectangular source emittance is deformed to a parallelogram in the slit coordinate (Figs. 3,4). The emittance with rf phase selected by slit S3 spreads well along S1 axis allowing relatively fine selections. The slit S2 selects emittance in a very close angle to the selection by S1. The dashed and dotted lines in Fig. 4 roughly shows the selection angles by two slits.

The slit S3 functions similar to the 180° slit(S2 in Fig. 5) of the dc measurement, since the S3 coordinate is a combination of transverse position in the emittance rectangle and rf phase, but is not sensitive to initial divergence, as seen from Fig. 3 (a).

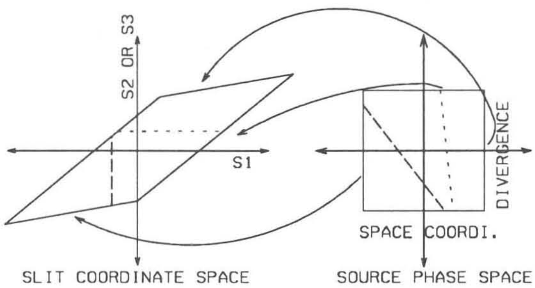

Fig. 4. Sketch of the transformation of boundaries from source emittance to slit coordinate space, The rectangular shape is deformed to a parallelogram.

To simulate the current distributions which will be actually measured in the experiment, a group of rays having uniform distribution in a rectangular phase space has been computed. The current distributions in Fig. 6 are obtained using the initial conditions in the second and third lines of Table 1 and actual slits of finite width. The phase slit S3 of 0.254mm wide is assumed fixed for both figures, and the scanning of slit S2 generates individual curves for a given S1 position. In Fig. 6 each point is the current measured at particular S2 position, and points are connected by straight lines (solid or dashed to reduce visual confusion).

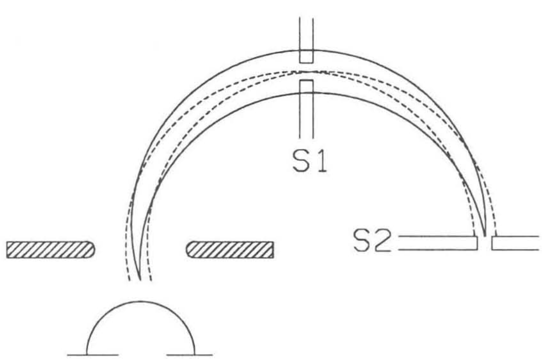

Fig. 5. The usual two slit method in the dc experiment.[3] The slit S1 selects the divergence, and the slit S2 scans the beam size. The S3 in our central region functions similar to S2 as initial divergence becomes less sensitive, while the beam spreads well by phase difference.

The distribution for the higher emittance(Fig. 6 , (b)) broadens along the S1 and S2 coordinates as expected from Fig. 3. The selections by slit S1 and S2 of 0.05 mm wide is demonstrated in Fig. 7 showing angled cuts in the source emittance, which is originated from the deformed transformation to the slit coordinate space. The selection by slit S2 is not as sharp as S1 as mentioned. The combined selections by two slits is sketched in (c) of Fig. 7.

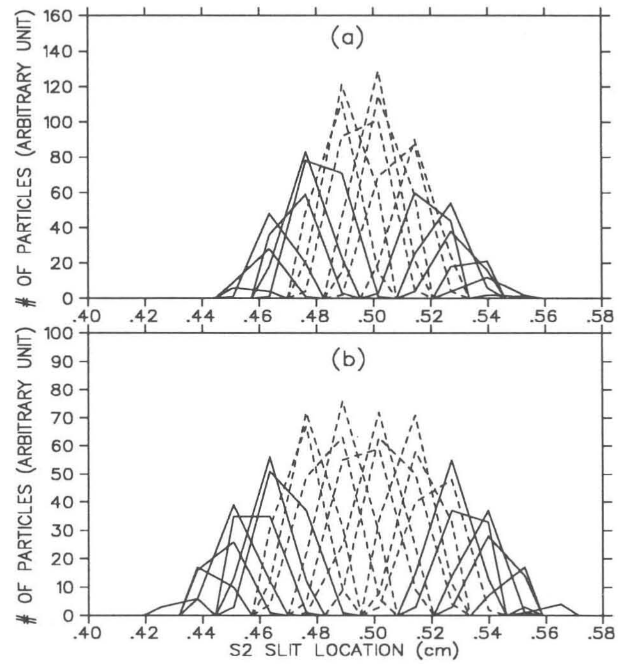

Fig. 6. The current distributions simulating the measurement are calculated for the initial conditions in the second and third lines of Table 1. The individual curves are obtained at different S1 locations as slit S2 is scanned. (a) has 19 curves(0.191 cm wide spread in S1 coordinate) , while (b) has 24 curves(0.267 cm wide spread).

The current and three slit locations measured in the experiment are the data to trace back to the corresponding emittance phase space and rf time. A large rectangular emittance which can cover the measurement and with a half degree step of rf phase, for instance, can be transformed to the slit coordinate, so the 3 dimensional meshes in slit coordinates will have the emittance and rf phase space range selected. (All calculations presented here are done at 8 tesla field which asks the most restricted design.)

3. DIFFICULTIES OF EXPERIMENTS

Since the planned magnetic field range is high(5-8 Tesla), and many ions do not clear the ion source, all dimensions in design are very tight. The difficulties anticipated in the experiments are;

1)The phase space coupling of radial and vertical motion may be a problem. We will try to minimize axial field in the central region by using structures which are high compared to the beam height.

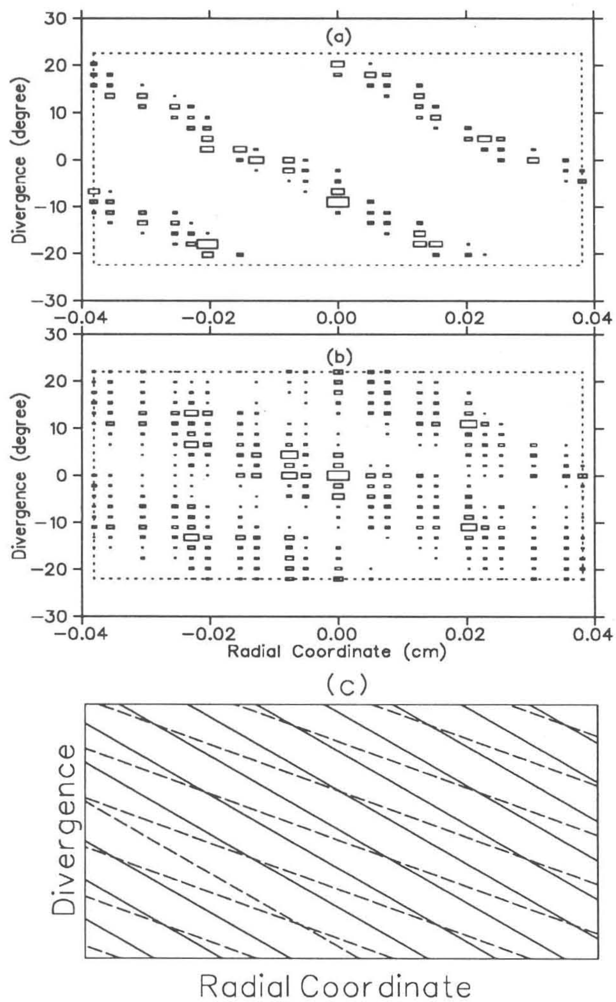

Fig. 7. The source phase space selected by slit S1 and S2 of 0.05 mm wide. The initial condition is same as the second line of Table 1 and with S3 fixed selecting τ around 215° - 225°. The three separated regions in each figure correspond to three different locations of S1 in (a), and S2 in (b) with the other slit scanned, respectively. (c) shows the sketch of pixels selected by both slits.

2)The space charge effect is not considered in present calculations, so the emittance measured includes the distortions which the space charge induces. (The rms source emittance usually appears worse than it is due to this effect.)

3)The deuteron used for calculations will contain molecules and other species in the real source; relative intensity is a function of plasma condition, and can be made small. We will check this with a dc measurement and tune the source to minimize other ions.

4. CONCLUSION

This study has the objective of measuring the time dependence of the characteristics of the ion source and the central region of the cyclotron. The central region of the study apparatus is designed to spread the beam by both emittance and phase. The radial source emittance (r,p_r) can be projected for the selected rf starting time by connecting the slit coordinates and the rf phase with a calculated map. The resolution of this method is limited by the available physical space at 8 tesla field, and as the rf starting time becomes late, the resolution decreases since the area occupied in the slit space shrinks. The selection angles by slits S1 and S2 are not orthogonal, and S2 doesn't separate the emittance space sharply. As a result the ideal resolving power is not achieved. In the situation of 8 tesla field and 50 kV maximum RF voltage, the present central region is believed to be an optimized one (even though further study may show other possibilities). In conclusion the three slit method works in calculation, but the actual resolution will depend on the slit size and an overall stability of the apparatus. We acknowledge the discussion with Dr. D.J. Clark(LBL) about the three slit system in the beginning of this project.

5. REFERENCES

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