CYCLOTRON ION SOURCE TESTING FACILITY†

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Summary. A facility has been set up for development and testing of cyclotron ion sources with special emphasis on capability for rapid phase-space density measurements. (As has been shown[1] the ultimate resolution which can be achieved in nuclear reaction experiments is determined by this density.) Ions from the test source are accelerated into a 60 kV D.C. "dee" and magnetically deflected thru 180°. A system of remotely adjustable slits are mounted inside the dee including: (a) an adjustable slit directly behind the puller to define the radial width and position of the beam, (b) a pair of adjustable slits located 90° from the puller, one defining the radial position, the other the vertical position of the beam and (c) an adjustable current collecting probe located at 180°. In order to permit testing of sources for heavy ions, a considerably larger magnetic field has been provided than is required for conventional sources (protons, deuterons, alphas). Ions with e/m ranging down to 1/30 can be deflected 180° with the dee potential at the full 60 kV; ions with lower e/m can be tested at reduced voltage. Polarities of both magnetic field and dee potential are reversible to allow convenient study of negative ion emission when desired.

Experimental Apparatus

Magnet

The magnet is an H-type magnet and has a 16" diameter pole. The shape of the pole tips was empirically determined; design criteria were: (a) the minimum gap should be 4", (b) ν_z should lie in the range from 0 to 0.05 and (c) the useful radius should be maximized. Two sets of pole tips were machined, one for field values of 3 to 5 Kg and one for 12 to 14 Kg. The magnet coils were wound from 0.425" square copper tubing (wrapped with "Scotch Ply") in double layer epoxy bonded pancake assemblies. The top and bottom coils of the magnet each consist of twelve 24-turn pancakes for a total of 288 turns. The coils are cooled with low conductivity water, including appropriate flow switch and thermostat. The current for the magnet coils is furnished by a regulated motor-generator set, which is capable of 655 amp output. A current of 600 amps is needed to obtain a central field of 14 Kg. The ion source is inserted thru the top of the magnet and its center is located 5.25" from the center of the magnet.

Vacuum System

The vacuum system consists of a 40 CFM mechanical pump and an 8900 CFM (at 0.1 micron) diffusion pump. The main vacuum chamber is an aluminum box with inside dimensions of 40"x20"x6". The sides of the box are welded, and the end plates are removable to provide easy access to the vacuum chamber. Windows and vacuum gauges are inserted in the box at various locations. The magnet pole tips enter thru the top and bottom of the chamber and the diffusion pump baffle is connected at one end of the chamber. An air-operated valve can isolate the chamber from the rest of the vacuum system. Pressure as low as 2×10^{-6} mm of Hg have been obtained using Narcoil-40 diffusion pump oil.

Ion Source

Figure 1 is a photograph of the disassembled ion source. Across the top of the photograph is the outer steel cooling jacket, chimmey housing, chimmey, and reflector button assembly. Across the bottom are the filament-lead assembly, filament, and heat shield. The outer jacket is 33.5" long and 1.375" diameter. The graphite chimmey is 4.5" long and its top 0.5" diameter. The chimmey slit is 0.800" long and 0.062" wide. The Tantalum reflector button is insulated from the chimmey by a quartz ring. Figure 2 is a cross-section drawing of the ion source. The dotted line area is glass epoxy laminate insulation, the slant lines steel. The filament assembly is constructed of two semicircular steel rods with copper cooling tubes (dark area) running in rifle drilled holes. An "O" ring is inserted between the outer jacket and filament-lead assembly to make the source vacuum tight. The filament is a 1/8" diameter Tantalum or Tungsten hairpin attached by set screws to the filament-lead assembly. The filament current is provided by a current regulated supply; typical operating current is 240 amps for Tantalum. The arc is driven by a constant voltage supply, typically operated at about 90 volts for arc currents of 0.5 to 5 amps. The white circular hole in the outer jacket (Fig. 2) is the gas line. The gas feed is controlled by a needle valve and measured by a Hastings mass flow meter. A typical flow rate for Hydrogen is 2 to 3 standard cc per minute.

Dee

Figure 3 is a photograph of the dee (with top plate removed). The dee consists of two copper plates about 16" square occuping a total axial height of 2.6". The dee is supported from the vacuum chamber by three hollow ceramic insulators. Cooling water is fed thru the ceramic insulators and into a manifold. The high voltage feed thru is a standard power line insulator, the center conductor of which consists of 12 #20 wires inserted thru a 3/8" copper tube and filled with epoxy to seal off vacuum leaks. The 12 wires terminate inside the vacuum chamber at a terminal strip and outside the chamber in a high voltage cage containing various meters. The dee power supply voltage can be varied from ±1 KeV up to ±60 KeV (in steps of 100 volts) and the current from 0 to 200 milliamps.

Puller, Slits and Current Probe

Figure 4 is a photograph of the puller, slits and current probe. The puller is at the bottom of Fig. 4 and the ion source would be located directly on its right in the figure. The slit in the puller is 1/4" wide by 1" long and the distance from the puller to the ion source can be adjusted. Just behind the puller is an initial radial and axial slit assembly called the "0^o slit". The slit mount and adjusting mechanism can be seen in Fig. 4; the radial position of this assembly is remotely adjustable across the full width of the puller. A second set of slits, located at 90^o (center of Fig. 4), consists of a pair of crossed slits, one at $+45^o$ and another at -45^o with respect to the horizontal plane. One lead screw moves the front slit relative to the back, hence changing the axial position to be scanned; the second lead screw moves both slits together, hence changing the radial position. Both slits are made of graphite and are remotely adjustable. The slits can scan a radial area of 2" and an axial area of 1". Located at 180^o (top of Fig. 4) is the current probe. The end of the current probe is a slab of graphite 1"x2"x1/8" with appropriate electrodes for trapping of secondaries and is designed to collect all current that passes thru the 90^o slits. The current probe is also remotely adjustable.

Computer Calculations

Uniform Field Comparison

Calculations using the Pinwheel[2] program for the CDC-3600 have been made to determine the orbit properties in the system. Input parameters to Pinwheel are the magnetic and electric fields, initial energy and initial location of the particle; using time, t, as the variable, output data consists of the coordinates x, y, p_r, and p_θ. Calculations were made for measured central magnetic field values of 13.5 Kg to 14.5 Kg and compared with uniform fields of the corresponding central field value. In both cases the electric field was assumed to be zero and the energy of the particles was varied from 49 to 51 KeV. All particles were assumed to start at 5.25" and injection varied from plus 1^o to minus 1^o with respect to the central beams, where the central beam starts perpendicular to the puller. Comparison between the momentum spread indicates that the actual field closely resembles a uniform field.

Phase-Space Calculation and Measurement

The phase-space density is a function of r, p_r, z, p_z, E, and t. To get a better understanding of this function, cuts of it are plotted. From the previous section, results indicate that uniform field approximations are valid; hence coupling between r vs. p_r and z vs. p_z is expected to be small. An r vs. p_r density plot is determined by the location of the 0^o and 90^o slits for given z and p_z values, the radial location of the 0^o slit defining the r and z of the beam and this slit is radially adjustable across the full beam to get a complete set of r values. The position of the 90^o slits with respect to the 0^o slit is known and, putting in the appropriate parameters to Pinwheel (see previous section), the p_r value can be calculated for each radial location of the 90^o slit. In like manner, the axial height of the 90^o slit determines the p_z value. The 90^o slits are radially adjustable across the full beam width and therefore gives a complete set of p_r values. Finally, the current probe gives the density information, i.e., the number of particles passing thru the 90^o slit per unit time. Adjusting the axial height of the 0^o slits gives a complete set of z values and adjusting the axial height of 90^o slits gives a complete set of p_z values. The energy, E, is determined by the potential on the dee. The energy spread, ΔE, is expected to be less than 100 eV and will produce a very small effect on the phase-space density. The exact value of this energy spread is also of minor importance since in accelerator design problems in which this information will be applied, the initial energy spread does not significantly couple to other degrees of freedom of the motion.

Conclusion

The present status of the facility is as follows. The magnet, vacuum system and ion source have been constructed and tested. The dee has been constructed and inserted in the magnet. At present, we are testing the voltage holding properties of the dee and making appropriate changes. It is expected that within the next month the slit system will be installed and initial phase-space measurements started.

References

1. B. L. Cohen, Rev. Sci. Instr. 33, 85 (1962).

2. M. Reiser and J. Kopf, M.S.U. Cyclotron Report-19, May 1964.

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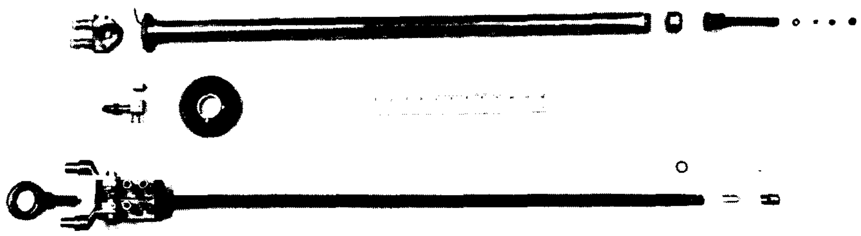

Fig. 1. View of disassembled cyclotron ion source. Top (left to right): outer cooling jacket, chimney housing, chimney, and reflector button assembly. Bottom (left to right): filament-lead assembly, filament, and filament heat shield.

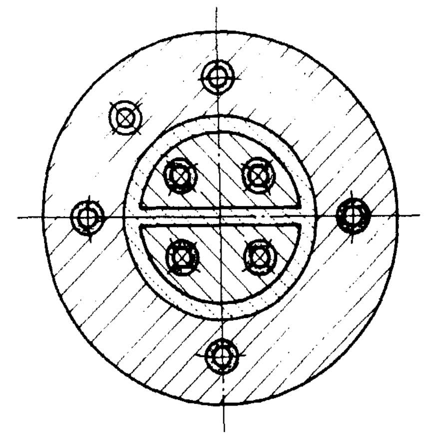

Fig. 2. Drawing of the cyclotron ion source cross section. The inner semicircular steel (solid-slanted lines) are the filament leads. The outer steel cylinder is the cooling jacket (O.D. 1.375"). The dashed lines are fiber glass epoxy laminate. The dark circular areas are copper cooling tubes and the light circular area is the gas line.

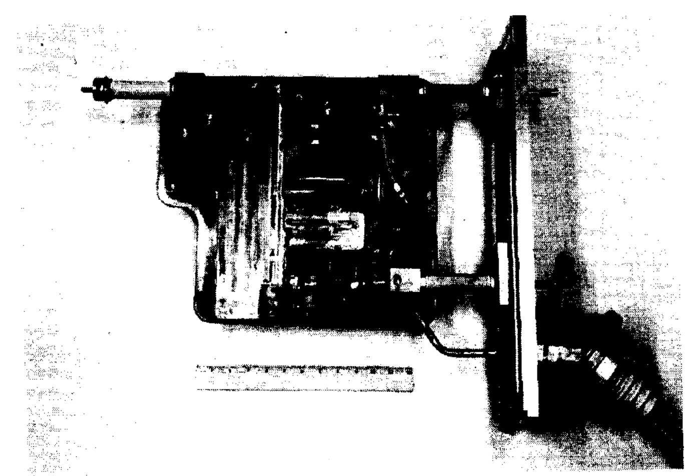

Fig. 3. View of ion source testing facility "dee" with top plate removed. The ion source is located at the indentation on the left side of the dee. The high voltage insulator is at the lower left.

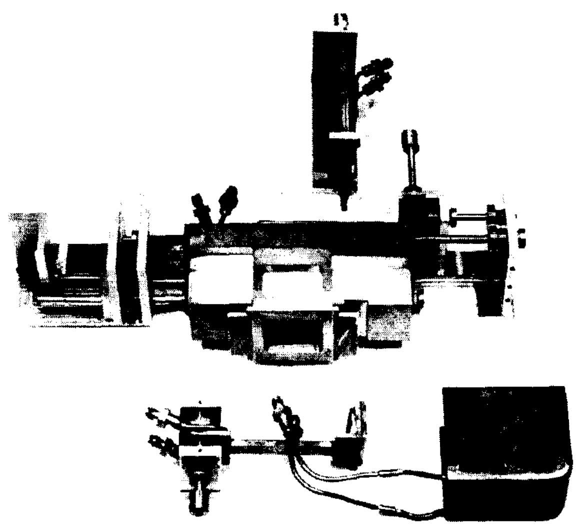

Fig. 4. Ion source testing facility phase-space density measuring apparatus. The ion source is directly in front of the puller (lower right). The axial and radial position of the beam is determined by the 0° slits (lower left); the axial and radial momentum by the position of the 90° slits (center). The current probe is located at 180° (top).