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BEAM PROBES FOR THE CHALK RIVER SUPERCONDUCTING CYCLOTRON

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Summary

The cyclotron has two internal beam probes that move in the midplane from outside the yoke to 135 mm radius. Interchangeable heads allow differential and integral beam current measurements of radial turn pattern or axial beam position and width, as a function of probe radius. Measurements on extracted beams will use one radial probe, a stub probe located downstream of the electrostatic deflector and an extraction probe that can be inserted up the beam line from just outside the yoke wall. The probes, the control system, and initial experiences with the system will be described.

Introduction

Several papers at this conference and others[1] describe the Chalk River Tandem Accelerator-Superconducting Cyclotron (TASCC) heavy ion physics research facility. This paper describes the four beam diagnostic probes associated with the cyclotron itself, and the microprocessor-based control system for them. The basic probe data consists of beam current readings as a function of probe position. The beams are expected to be 2 mm wide and 8 mm high, with turn separations of 3-10 mm. Figure 1 shows the outline and certain salient features of the cyclotron. Also shown are the four probes: radial probes 1 and 2, stub probe, and extraction probe.

Radial Probes

The two radial probes are mechanically and functionally identical. Each consists of a probe tube with a beam measuring head on its tip that is moved, in the cyclotron midplane, along a straight line 40 mm offset from the cyclotron center. Probe tip travel is from 135.0 to 2000.0 mm radius. Probe 1 is at 53° azimuth (relative to the cyclotron reference 0°) which places it 29.6° downstream of the stripper foil. It also crosses the extraction beam line at the yoke outer wall and can be used for measurements there. Probe 2 is 90° downstream of probe 1, thus 51° upstream of the entrance to the electrostatic deflector.

Figure 2 shows one radial probe (numbers in brackets refer to numbers in the figure). Each has a separate vacuum system and isolation valve (1) to facilitate probe changes. Turbomolecular (2) and direct-drive rotary pumps are used. The outer end of the probe tube fastens to a movable carriage (3). The edge-welded bellows (4) that forms a moving vacuum envelope is 102 mm outside diameter, consists of 10 sections with rigid plates between them and has a maximum length of 3.0 m and a minimum length of 0.6 m. The bellows is supported by eleven hangers (5) (one fastened to each rigid plate) that roll on a carrier rail (6) just above the bellows. The probe drive carriage is on guide rails (7) and is driven by an 0.250 inch (6.35 mm) per revolution ball screw (8) coupled to a 200 pulse per revolution stepping motor (9). The drive screw also drives an absolute, 1024 pulse per revolution shaft angle encoder (10) through a 6:1 reduction gear. With this combination the desired probe position resolution of 0.1 mm corresponds to about 3 motor pulses and 3 shaft angle encoder pulses. The stepping rate of the probe scan motor has been set to 150 pulses per second, which gives a traverse rate of 4.76 mm/s.

Several features facilitate probe use. The first involves knife-edge bars (11), mounted in the vacuum chamber opposite a viewport, that allow probe tip positioning to be checked or reproduced. A zero offset feature of the shaft angle encoder interface

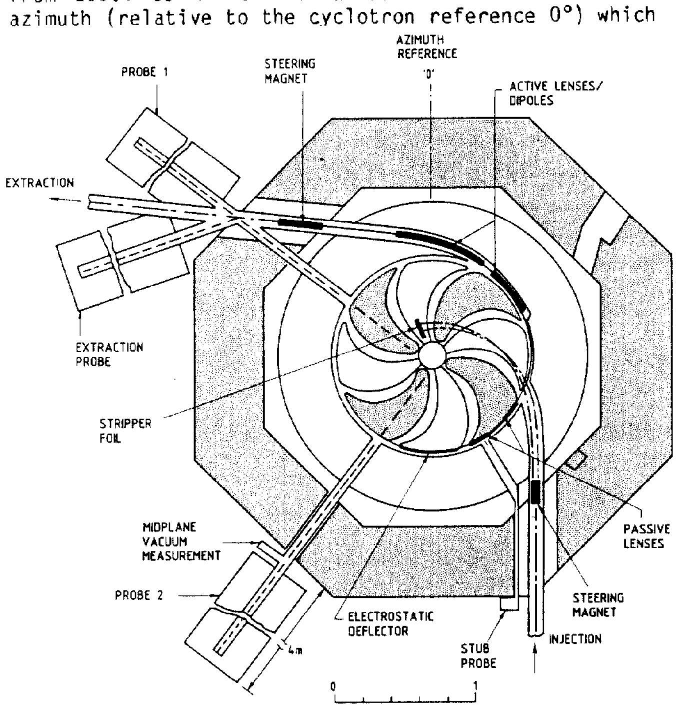

Figure 1. Locations of the cyclotron probes.

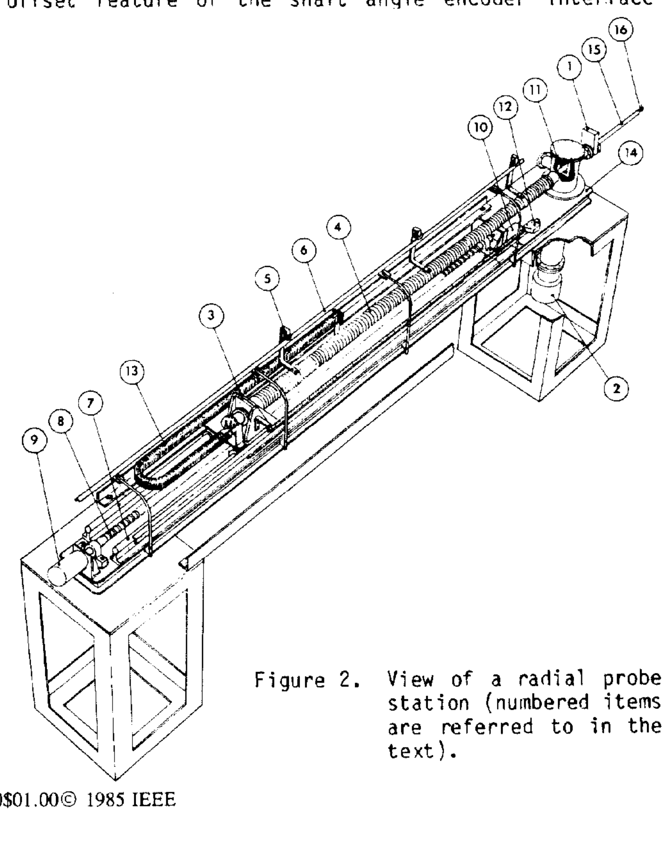

Figure 2. View of a radial probe station (numbered items are referred to in the text).

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allows resetting of the displayed probe position value to correspond to the known probe tip position. A second feature is that the body of a retracting measuring tape (12) is mounted near the vacuum chamber, and its tip fastened to the carriage. The tape gives a visual indication of probe position and also serves to interrupt the light beam in five optical switches located along the probe travel range. This system gives, even upon system power-up, unambiguous definition of probe location (i.e., full out, in-past-gate, in-past-intersection, full in, and in-for-change). Thirdly, a commercially-available flexible conduit (13) houses signal cables and water hoses leading from the probe carriage to the probe strongback (14), thus reducing wear-and-tear and preventing fouling.

Interchangeable probe tubes (15) mount on the probe drive mechanism. Each is 3.2 m long and 24.5 mm in diameter. Probe heads (16) mount to a water-cooled copper bar at the tube tip. Six rigid coaxial cables lead from the probe tip to the outboard end where connections to flexible coaxial cable are made through a vacuum seal.

The probe heads, shown in Figure 3, are made of TZM alloy molybdenum with boron nitride insulators. Secondary electrons are collected by ridges or plates at the top and bottom of the probe head elements. Radial measurements are made using a 0.25 mm diameter, 19 mm long, vertical tungsten-10% rhenium wire located 3 mm from the end of a 19 x 30 mm plate. The two types of axial head have five 3.0 mm wide bars, located one above the other with 1 mm between them, protruding 1 or 3 mm respectively from behind a 19 x 30 mm plate (only the 3 mm version is shown in Figure 3).

Stub Probe

The stub probe is located on the path of the extracted beam, at 213° azimuth, which is behind the first passive lens and 20° downstream of the electrostatic deflector exit. This probe acts as a beam stop and as a diagnostic element for the deflector. Its head (see Figure 3) consists of two staggered plates that give left-minus-right and total current information. The stub probe is moved from full-in to full-out by an air cylinder. An edge-welded bellows, located in a recess in the cryostat inner wall, makes the vacuum seal.

Extraction Probe

The extraction probe has not been completely designed yet, but preliminary tests of concepts have been made, basic equipment ordered, and provision for incorporation into the control system made.

Probe Control System

The TASCC facility control system is based on a system used at the VICKSI facility at the Hahn-Meitner Institute, Berlin[3], and uses a PDP 11/44 computer, serial CAMAC highway, and CAMAC crates and modules. The use of a CAMAC-based LSI-11 microprocessor for the diagnostic probe control system is forced by the large volumes of position and beam current data that must be handled in real time.

The probe control system includes both equipment interlocking and data-taking functions. Figure 4 is a block diagram of the system. The first of two CAMAC crates is controlled by an L2-type controller connected to the serial highway. This primary crate also contains an Interface Standards IS-11 auxiliary crate controller, mass memory driver, mailbox memory, and bus extender, all interconnected via Q-bus signals. The secondary crate is connected only via the Q bus signals and an IS-11-CC crate controller. Commands originating in the TASCC control system address locations in a 64 word auxiliary memory on the dataway of the primary crate. The memory then interrupts the microprocessor which acts upon the command. Similarly, status words are placed in this memory by the microprocessor, for use by console operators via the touch panel system.

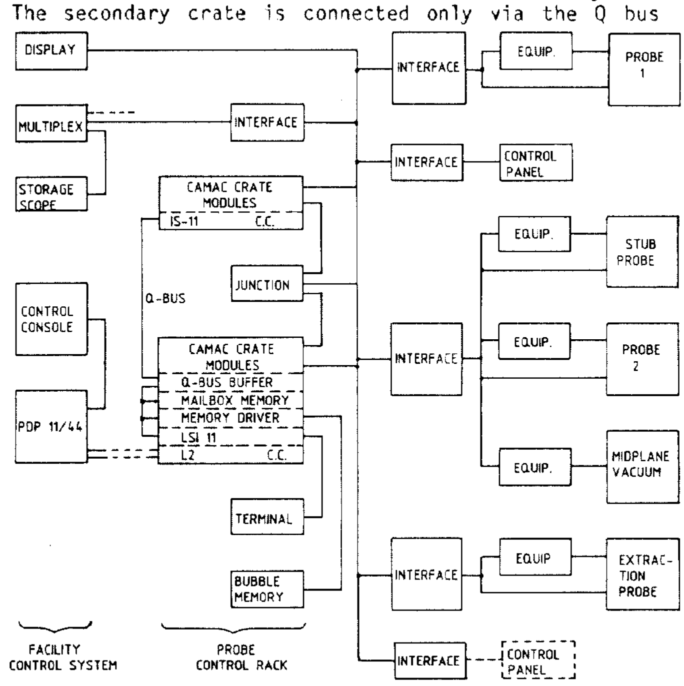

Figure 4. Control system layout.

The DEC RT-11-SJ operating system is used, all

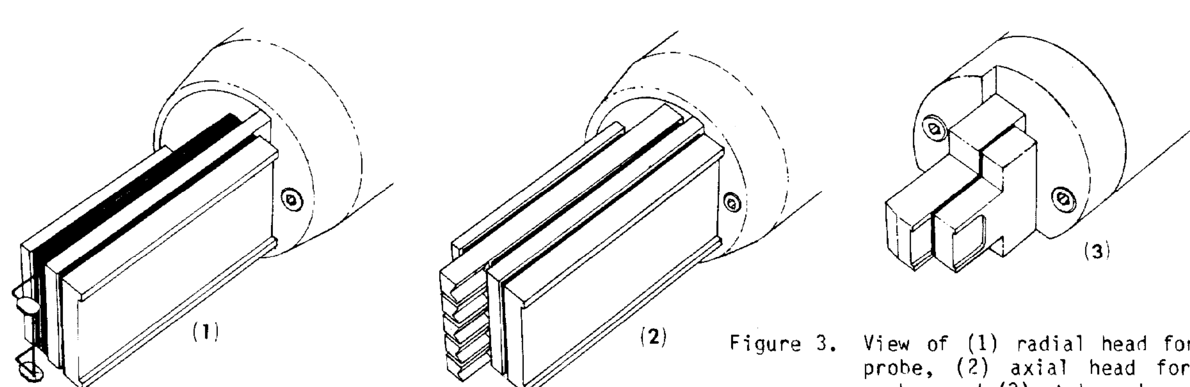

Figure 3. View of (1) radial head for radial probe, (2) axial head for radial probe, and (3) stub probe.

user programs are written in FORTRAN, and routines for CAMAC operations were supplied by Interface Standards. Considerable effort has been required to keep the user code within the 64 kbyte LSI-11 memory.
The control program consists of a very short main program and 25 subroutines. The main program calls a system initialization routine, then enters a routine TIMER that loops indefinitely - waiting for interrupts that call up actual system control and data-taking routines, and updating vacuum and position readings every 2 seconds. Status changes trigger interrupts in the microprocessor, which then reads all status, recalculates interlock equations, readjusts system controls and state as appropriate, and stores certain status words in the auxiliary memory.

System Operation

Commands from console operators, sent to the microprocessor via the auxiliary memory, can specify the details of probe movement; data collection, storage and display; and operate the vacuum isolation gate valve, service water valve, and ion gauge filament on/off. Manipulation of other vacuum system components is not possible from the console.

Operators working on the cyclotron floor can control the probes using a small, dedicated terminal. The membrane surface of the keyboard is overlaid with legends describing functions. For example, in turning on a roughing pump, the operator presses four keys having the legends "Probe 1", "Roughing Pump", "On/Open/Out", and "Enter". The incoming four-character message is decoded, four sixteen-character responses are sent for display on the terminal's 64 character LCD display, and subroutines for required actions and responses are called. A status bit prevents the two sources of control signals (control room and local) from being simultaneously acted upon. Illegal command sequences are detected. Commands available at the local station include: operation/status of all vacuum components, certain probe movements (move in, move out, read position), water and vacuum interlock by-pass and services on/off/status, and probe head type specification. The probe head type is entered by an operator so that operators at the main console and the system subsequently know which type of measurement is possible and allowed.

The system terminal shown in Figure 4 is used for access to the RT-11 system and for typing out system messages.

Beam Current Measurement and Display

Currents intercepted by probe tip components are routed through simple RC network rf filter boxes to current-to-voltage preamplifiers. The Danfysik 548 amplifiers used have externally-selectable ranges of 10^{-4} to 10^{-9} A full scale, and produce 5 V out for full scale current input. The amplifier outputs are input to the ADC module. The operators may select an autorange mode (implemented in software), a test mode, or a fixed range for the amplifier gains. The fourteen amplifiers are arranged in two groups: those set to range A are connected to probe components intercepting full beam current, and range B amplifiers are used to detect differential currents. The programs cross-check probe head type against which currents were selected for display; only relevant amplifiers are considered in the autorange procedures and data taking can start only if parameter selections are compatible.

The requirement for real-time data flow forces use of a dedicated display panel in the main control room with signals sent directly from the microprocessor system. This panel has: digital display of the positions of probes 1 and 2 and the extraction probe, LED displays for stub probe in/out, and two sets of coupled analog and digital meters. Any of the following currents can be sent to either pair of meters: main probe total current, radial differential current or axial differential current on any of the five bars; main probe axial centroid (calculated from the five axial differential currents), stub probe left-minus-right or total current, extraction probe left-minus-right, up-minus-down, or total current.

Probe scan data can be displayed on a storage oscilloscope at the console. This scope serves several purposes in the overall control system but a two-way multiplexer at its input is commandeered by the probe control system when required. Plot controls available to the operator are: which radial probe current to display (same choices as for meters but including a scan of all five (rather than individual) axial head bar currents), x (position) scales as 800, 200, 50 or 20 mm per screen width, and y (current) scales of 1, 1/2, 1/3, 1/4 or 1/5 screen height. The program checks the selected x scale and scan distance, and adjusts the y scale if necessary to give multiple rows of reduced-height display. Axes are drawn on the screen prior to each new scan.

The parameters defining head type, which probe is being scanned, and which data are being displayed on the oscilloscope determine the data to be stored in a 64 kbyte mailbox memory. Data for each scan consists of date, time, and scan parameters, followed by position then total and differential currents for each data point. A program executed through the TASCC facility computer transfers this data to the CRNL site computing facility for detailed analysis.

Operating Experience

At the time of writing, the probes have not been used with beam but preliminary operation with probes 1 and 2 and the stub probe has been satisfactory.

The control system has been used extensively during the commissioning of the probe system. The control system is versatile, self-explanatory, and provides equipment safety. The mechanical systems are also easy to manipulate.

Acknowledgments

Early work on concepts for the probe system was done by P.M. James and J.H. Ormrod. J.H. Ormrod, C.B. Bigham, E.A. Heighway, C.R. Hoffmann and J.A. Hulbert have provided useful comments on an ongoing basis. D.G. Hewitt and J.F. Weaver did some interesting mechanical development on the stub probe and the radial probes respectively. Other cyclotron group members have been of help in either design or installation of the probes.

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