

be accelerated to about 290 MeV. This beam has been accelerated to 270 MeV, and development at the higher energy awaits a user request for the beam. The present operating limits of the cyclotrons are summarized in Table IV. Polarized protons and deuterons are designated  $\bar{p}$  and  $\bar{d}$ .

- 1) 1983 Scientific and Technical report, p. 184.
- 2) This report, p. 176.
- 3) 1983 Scientific and Technical Report, p. 198.

- 4) A Low Energy Storage Ring for Pulse Stacking at IUCF, D.L. Friesel, R.E. Pollock, T. Ellison, and W.P. Jones, Proc. 10th International Conf. on Cyclotrons and their Applications, (East Lansing, MI, April 1984) F. Marti, Editor, p. 207.
- 5) Pulse Stacking with a Low Energy Storage Ring, D.L. Friesel, R.E. Pollock, T. Ellison, and W.P. Jones, Conf. on the Applications of Accelerators in Research and Industry, (Denton, TX, Nov. 1984) to be published in Nucl. Instr. and Methods.
- 6) 1983 Scientific and Technical Report, p. 188.
- 7) D.L. Friesel, W.P. Jones, and J.C. Collins, IEEE Trans. Nucl. Sci. NS-26 (1979) 3389.

#### LABORATORY DEVELOPMENT

##### Accelerator Improvements

Through the continued implementation of the facility manpower reorganization plan started last year, the majority of the laboratory efforts during 1984 were directed toward the new construction and upgrade projects while simultaneously providing the minimum support required for maintaining an ongoing research program whose technical needs are becoming increasingly complex. The manpower reorganization required to accommodate this shifting workload while maintaining a nearly normal cyclotron operating schedule, which is described in the preceding sections, was put into full operation this year with satisfactory results. The necessary consequence of these changes was that the continued upgrade of the existing accelerator facilities have temporarily been given a lower priority than in previous years, and will only be accomplished in the near future as the workload of the operations and maintenance group permit. This situation is only possible because of the present smooth and reliable operation of the accelerators, which is due in large part to the success of the retrofit work to the existing facilities that was

carried out over the last three years. To meet the construction demands of the new projects, several of the laboratory supported accelerator upgrade projects started during the previous years were terminated prior to their completion (mainly the rf system upgrades). Several others, however, which were very near completion, were made operational this year. In addition, a few accelerator system improvements were also accomplished by the operations and maintenance group. The computerized maintenance program development begun last year by this group, for example, was completed and put into service. The success of this effort led to the development this year of a companion program to simplify the inventory and ordering of spare parts and other consumable materials required to keep the cyclotrons operating efficiently.

One of the larger upgrade efforts currently underway which has an immediate impact on the operation of the cyclotrons is the installation of the hardware for the new cyclotron control computer. This work, which is described later in this report, has progressed so that several technicians can switch

control of the cyclotrons from the old Xerox Sigma II computer to the new PDP 11/44 computer in about one hour. The switchover includes the replacement of the existing computer display apparatus at the control console. After several attempts to control the cyclotron systems with the new computer, it appears that the software and hardware debugging of this system is nearly complete, and that operations with the new computer will begin in 1985. The progress of this effort has been somewhat slowed recently by the need to schedule cyclotron beam time to test fully the new controls system.

Related improvements at the control console were made during the year which expanded the rack space by 60 ft<sup>2</sup> to provide additional room for new diagnostic systems for the stripper loop and wall-current monitor developments and for the anticipated future needs of the cooler diagnostic and controls equipment. A consolidation of the existing cyclotron control and diagnostic systems at the console was also implemented. The rather bulky capacitive phase control system for all the cyclotron rf systems were replaced with new electronic phase shifters, and new smaller rack mounted oscilloscopes were installed to replace the original large scopes. The new phase shifters not only required less than 25% of the rack space, but they have a frequency independent operating range of 400 degrees and a factor of 20 improvement in the phase adjustment resolution. Phase adjustments over the entire range are made manually with small 10 turn pots and over 20% of the range through the controls computer. In addition, a new distribution system for the various cyclotron rf reference signals (the fundamental frequency from the synthesizer, and the adjustable sub-harmonics needed for the stripper loop, bunchers and choppers) was installed in the control room to

increase the amplitude and stability of the signal levels and to provide a much needed supply of accessible spare outputs for new equipment and also for the users.

Several safety-related improvements were made this year in a continuing effort to protect equipment from fire losses. An automatic Halon system was installed in the CSB electronics huts, improvements were made to the Halon system for the main cyclotron magnet power supply (alpha 14), and a routine inspection schedule for all fire suppression and smoke detection systems was instituted. An Addemco automatic dialing system to report all fire alarms to the university physical plant 24 hour control center was also installed in the control room. Tunnel entrance areas were made safer by replacing heavy steel doors with aluminum ones and improving access to them. An inspection of the 30 ton overhead bridge crane revealed serious faults with the rail support structure, which required some repair and reconstruction. This inspection and repair was particularly timely because of its heavy use in the assembly of the dual spectrometer magnets.

Much of the accelerator improvement work this year was done in the ion source room. In efforts to improve the voltage holding ability and stability of the small ion source Terminal B, a new gradient resistor and guard ring assembly to replace the original water resistor on the accelerator column was fabricated and installed. Grounding for the Faraday cage, terminal base and high voltage power supply was improved by the addition of a wide copper shield to improve the spark protection for the surrounding equipment and the new controls computer. A new precision Haefely voltage divider, which is identical to the one previously installed on Terminal A, was also installed on Terminal B to replace the failure prone internal voltage

reference for the 600 kV power supply. In addition to improving significantly the reliability of the power supply, the new voltage reference has improved the voltage regulation and setpoint reproducibility of the power supply. Long standing small but irksome problems with the Terminal A hydraulic system which drives the alternator were understood and eliminated this year after several failures. A member of the operations and maintenance group was sent to an intensive three week hydraulics training course given by McVickers, the manufacturer of the system. It was learned that both the main and servo pumps of the hydraulic alternating drive unit had worn to the point where it could no longer spin the alternator fast enough to provide the power required to operate the sources. Rebuilding the pumps and improving the filtering of the oil used in them has virtually eliminated all the problems we have had with the system. Furthermore, we now have the expertise in house to diagnose and repair this system effectively.

Other improvements to the ion source room included the installation of the  $H^-$  inflection magnet and vacuum chamber on the stripper loop mounted in beam line one and the completion and debugging of the  $f/2$  buncher drive and low level electronic controls systems. The beam development of these two systems are discussed in the previous section. Their recent addition to this beam line helped create a shortage of deionized cooling water outlets, which was corrected by rebuilding and relocating the water distribution manifolds throughout the ion source room. This long needed improvement not only increased the cooling water capacity to meet the requirements for the foreseeable future, but also provided the opportunity to improve the efficiency, accessibility and labeling of the manifolds and flow switch interlocks, which has simplified the servicing

of the beam line one systems during maintenance shutdowns or emergency repairs.

Relatively little work was done on the injector cyclotron this year. The major improvement in this area was the design and installation of a new rf tuning panel drive motor control system which detects and corrects differences in the positions of the upper and lower tuning panels relative to both the north and south rf resonators. Prior to the installation of this new control system, slippage of the stepping motors caused the tuning panels to become asymmetrically positioned above and below the resonator. The asymmetry frequently had to be manually corrected when operation at the upper and lower frequency ranges was required. A fine control for the injector magnet power supply (alpha 20), which is 25 times more sensitive than the original control, was installed to allow the operators to maintain a constant field without disrupting the cyclotron tune. This is particularly useful for centered beam operations and will eventually be controlled by a feedback signal from the beam phase or magnetic field measurement system presently under development. An identical fine DAC control was installed on the main cyclotron magnet power supply (alpha 14) as well.

Of the several improvements made to the main stage cyclotron, the most significant was the continued reduction of the rf interference problems (rfi) which adversely affected the stability of the main cyclotron magnet and trim coil power supplies. This program began last year by enclosing all the main cyclotron rf low level and drive signals in steel conduit. The main drive cable for the east resonator was found to be damaged during this work, and was replaced this year with a new cable. It was also discovered that the DAC control cables for these magnet supplies were not only

picking up noise from the rf system, but were also sensitive to the activation of the overhead bridge crane motors (480 V ac), the f/3 splitter magnet system under test on the rf balcony, and the high current power supplies for the dual spectrometer magnets which are now being field mapped in the middle high bay area. These interferences were eliminated by similarly rerouting and enclosing all DAC and ADC cables for the control of these power supplies in steel conduit. While the stability of the main cyclotron magnetic field has been further improved by this measure, small but observable field changes still occur when energizing the dual spectrometer magnets during field mapping operations and by the passage of the bridge crane over the main cyclotron vault. These were determined to be real magnetic field interferences, however. This was verified for the bridge crane, for example, by observing that the magnitude of the field disturbance is proportional to its velocity when passing over the main vault, and that if the motion is slow enough, no disturbance is seen at all. On the main rf system itself, a multi-position switch was installed to select the frequency dependent length of the rf drive cables from the 1 kW tuned amplifier. This used to be done by trial and error by hand at the back of the rf cabinets when rf frequency changes were required for machine energy changes. Other improvements in the main vault area include the installation of a new water manifold for all cyclotron auxiliary magnets, such as the axial harmonic coils, and the inflection and extraction compensators and magnets. As in the ion source area, the many additions and changes made over the years caused a shortage of cooling water outlets, and a rather haphazard placement of the water flow interlocks. This situation was rectified by the installation of the new manifolds.

The reliability and longevity of the four upper 20" cryodynes have continued to improve during the year. Maintaining the main cyclotron vacuum with the two 36" diffusion pumps and the intermittent use of these valuable cyropumps has worked very well throughout the year. During emergency repairs which require breaking the main cyclotron vacuum, pumpdown times of as little as two hours were achieved with this system. This is significantly faster than the eight hour pumpdown times required by the lower cyo-pumping system which is no longer being used for routine operations. Inside the main stage cyclotron, the electrostatic deflector entrance and exit drive mechanisms were modified to reduce the torque required to move them to stop a troublesome tendency to stick occasionally, and the design of the rotating ground connection for the turn pattern wire scanner was improved to reduce noise and to improve its useful lifetime.

There was considerable activity in the high energy beam line areas this year as well. The implementation of the beam splitting system in beam line 3 began with the installation of the vacuum chamber and first two of the four required Lambertson splitting magnets. This installation required the relocation of quad 1 in beam line five and the beam stop immediately following the momentum analysis slits in beam line 4. Several wall-current pickups were installed in beam lines 2, 3 and 6 to monitor the beam phase and pulse structure. The monitors were installed to develop their use for the cooler, but were soon determined to be so useful for routine operations that these installations have become permanent. Details of these efforts are discussed later in this report.<sup>1</sup> Also, as the needs of the spin transfer experiments have dictated, several new high energy polarimeters were installed in beam lines 5 and 7 to measure the direction of the

transversely polarized proton beams from the cyclotrons.

1) This Report, p. 121.

### Ion Sources

The polarized ion source ran very reliably in 1984 operating for a total of 5142 hours or 643 shifts. This year approximately 60% of the running time was polarized protons the remaining 40% being polarized deuterons. Average beam intensity from the source is still about 6  $\mu$ amps. Again this heavy running schedule afforded little time for source upgrades.

The effort to get the Stanford Superionizer tested proceeded as follows. The source was under reconstruction from September 1983 to May 1984. We saw our first beam in May 1984; the intensity being only 7  $\mu$ amps of  $H^+$  of which 5  $\mu$ amps were background. During talks with P.-A. Chamouard and R. Vienet of Saclay they pointed out that our  $1 \times 10^{-6}$  Torr vacuum was not good enough. They also pointed out that their superionizer did not work well until they had realigned the solenoid coils to remove radial components from the magnetic field. The next few months were spent in trying to improve the vacuum in the Superionizer by adding Cryo-pumps and Ti-ball pumps. In addition, a realignment of the Separator Sextupole was necessary. The best operating pressure we were able to attain was  $7 \times 10^{-7}$  Torr. A residual gas analyzer on the system showed that we had sodium contamination in the ionizer. This, of course, was to be expected since this source was run at Stanford with a sodium charge exchange canal in order to produce  $H^-$  beams. Even though the system was thoroughly cleaned some sodium still remained which kept our operating pressure higher than desired.

Eventually the highest beam intensity attained was 12  $\mu$ amps of  $H^+$  with 4  $\mu$ amps of background. Due to a previous commitment to deliver the Atomic Beam Section of this source to the University of Wisconsin, enough time wasn't available to realign the solenoid magnetic field and make further tests.

It is probably possible to continue testing the Superionizer using molecular hydrogen but for the moment we have suspended work in this area in order to devote our attention to other more pressing matters.

The stripper loop development would like to have an  $H^-$  beam from the Duoplasmatron. To this end all our electrostatic supplies in Terminal B have been replaced with bipolar supplies. A first attempt to get  $H^-$  with an off axis extraction Duoplasmatron produced  $\sim 15$   $\mu$ amps of beam. Of course higher intensities are needed and are hoped for from such a source. Using equipment left over from the Superionizer development we intend to set up an  $H^-$  test station in order to improve the  $H^-$  beam intensity.

In the Polarized Source another attempt at cooling the dissociator bottle nozzle will occur next year. This time we intend to use not only the 20°K 2 watt shield of the Cryodyne but also the 70°K 7 watt shield. It is hoped this added cooling power will keep the nozzle from warming up after it has been running for awhile. The dissociator nozzle was redesigned and a first test has been made with a room temperature beam. The new nozzle produced a normal intensity beam unlike our previous cooled nozzle geometry.

A new set of corona rings were designed and installed on the Terminal B acceleration column. It is still necessary for us to get some operating experience with them before we can decide whether or not the voltage holding capabilities of the column have been

improved. We have also installed a new Haefely precision feedback resistor on Terminal B for improved high voltage regulation.

#### High Energy Polarimeters

Because of the increased demand for polarized deuteron beams at energies other than 80 MeV, we have improved the performance of the beam line 2 polarimeter and extended the energy range of its calibration. The polarimeter will continue to use the  ${}^3\text{He}(d,p){}^4\text{He}$  reaction as the reference standard. The detectors have been moved from a lab angle of  $67^\circ$  to  $30^\circ$ . While the tensor analyzing power at this new angle is slightly smaller, the vector analyzing power is larger, and both remain large over the extended range of the new calibration. The count rate has increased a factor of 2.5, making polarization measurements faster and more statistically precise.

The absolute calibration was repeated at 80 MeV, and reproduced previous values to about 1%. This calibration is based on observing the  ${}^{16}\text{O}(d,\alpha){}^{14}\text{N}$  reaction to the first excited  $0^+$  state in  ${}^{14}\text{N}$ . Because the scattering matrix for this reaction has only one free amplitude, the analyzing powers are fixed, independent of scattering angle and bombarding energy. With  $A_y=0$  and  $A_{yy}=-2$ , only the tensor analyzing power is useful. The calibration reaction was observed with a gas cell containing thin exit windows and silicon surface barrier detectors operated with only a few volts of bias. The reaction is isospin forbidden and proceeds only when there is sufficient mixing of the compound nuclear states. This yields a small cross section that fluctuates with bombarding energy. The cross section was large enough to make a precise calibration only when the injector cyclotron was tuned

for the 80 MeV deuteron beam. This calibration was transferred to the vector analyzing power by assuming that the ratio of tensor to vector polarization for the strong field transition units in the ion source is exactly 3.

The calibration was extended to other energies by tuning the cyclotron for the 95 MeV deuteron beam, and repeating the polarization measurements with various thicknesses of energy degrader foil in front of the polarimeter. Using the 80 MeV calibration as a reference, it was then possible to determine the energy dependence of the tensor and vector analyzing powers. The results are shown in the Fig. 6.

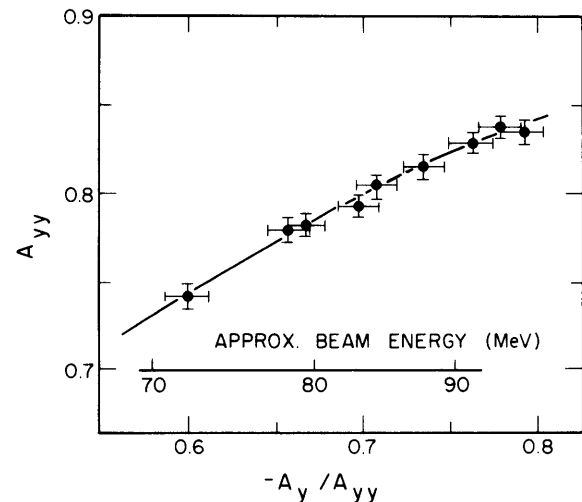


Figure 6. The calibrated tensor analyzing power of the beam line 2 polarimeter, shown as a function of the ratio of the vector and tensor analyzing powers. The use of this calibration is described in the text.

Since the injector cyclotron energy cannot be precisely measured, it is necessary to establish another scale for determining the correct calibration. We chose the ratio of the vector to the tensor analyzing power. This ratio is obtained from the usual polarization measurement by assuming that the tensor to vector polarization ratio for the strong field transitions is 3. Reference to the Figure then gives the scale of the tensor analyzing power, and from the

ratio one can obtain the scale of the vector analyzing power. The approximate beam energy (with an error of 200 keV) is noted on the Figure.

#### Beam Splitting Development

The beam splitter will be of benefit both to the cyclotron research and to the Cooler and is partially supported by both budgets.

Substantial progress was made this year on the hardware developments required to implement a beam splitting system which will allow the simultaneous operation of the cooler with conventional cyclotron experiments. This is an important development which will not only minimize the impact of the forthcoming Cooler beam development work on the ongoing research program here, but will also immediately benefit the conventional user by providing beam to just about any two of the existing experimental areas simultaneously. In this mode, a fraction of the cyclotron beam can be diverted away from a primary user to perform detector tests or to facilitate the electronics setup for complex experiments. When circumstances warrant, the splitter can also be used to deliver beam to two experimenters simultaneously. The beam splitting plans call for an rf magnetic beam deflector operating at  $1/3$  the cyclotron rf frequency to provide a 6mm horizontal separation between one of every three cyclotron beam bursts at the entrance to a series of four Lambertson septum magnets located 3m downstream. A plan view of the beam splitting apparatus in beam line three is shown in Fig. 7, along with a view of the entrance port for each of the four Lambertson magnets showing the possible beam trajectories. The septum magnets further separate the trajectories of the split beams by a combination of vertical and horizontal deflections which cause them to be delivered simultaneously to one

of the experimental areas in any two of the three beam line branches shown (BL 4, BL 5-6-7 or -8, and BL 9). For the continuous operation of the  $f/3$  splitter magnet, the ratio of the beam intensities delivered simultaneously are constrained to be 2 to 1.

A prototype Lambertson septum magnet, which is similar in design to the type needed in the inflection and extraction regions of the Cooler ring, was fabricated in house this summer and developed into a design suitable for use as the first (L1) of the four splitting magnets in beam line three. In the end view of this magnet shown in Fig. 7, the low field region is in the notch in the return yoke on the right, and the high field region lies on the other side of the knife edge. Several modifications to the original design were required to reduce the fringing fields at the magnet ends and to increase the magnetic field ratio between the high and low field paths from an initial value of 10 to over 300. Because these magnets are relatively short (20 to 30 cm), the effects of the fringe fields at the magnet ends cannot be ignored in our application. While the field ratio of the prototype magnet is acceptable for operation in the beam line three splitting system, a factor of three improvement is needed for use in the Cooler. The results of this design study were recently presented at the 10th International Cyclotron Conference.<sup>1</sup>

The second and third Lambertson magnets (L2 and L3) in the series were also fabricated and tested. Because of the difficulties involved in constructing a practical vacuum chamber for each magnet, it was decided to mount all four magnets inside a common vacuum chamber which also contains the stops and viewers needed to thread the beam through the maze. This chamber was fabricated and installed in beam line three along with the first two Lambertson magnets (L1

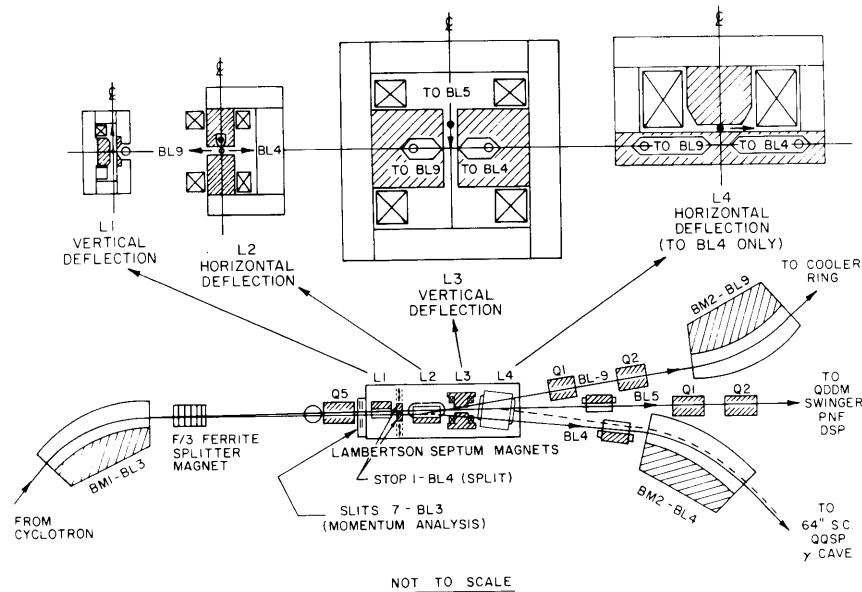


Figure 7. Plan view of the beam splitting system.

and L2) during the ten day shutdown in July, 1984. Brief beam development studies<sup>2</sup> demonstrated that the field ratios obtained were adequate and that 100% transmission of beam through the various trajectories was possible. The third Lambertson magnet is presently being field mapped. The fourth magnet (L4), which has yet to be fabricated, is not required for the initial beam splitting capabilities described above. The purpose of this magnet is to provide for the simultaneous delivery of beam to any of the three experimental areas in beam line four (64" Scattering chamber, Gamma cave, or QQSP) and to the Cooler or to any two of the areas on BL4. This option has a low priority at present.

Perhaps the most critical element in the beam splitting hardware, however, is the f/3 ferrite kicker magnet which must provide the 6mm beam path displacements at the entrance to the first septum magnet. During the summer, the ferrite material (Ferroxcube Type 4M2) for the kicker was assembled and tested. For the effective magnetic field length

permitted by physical constraints in the beam line, a magnetic field amplitude of 41 gauss is needed to provide the necessary horizontal beam separation. The kicker magnet is basically an H frame magnet with one-turn 1/4 wave balanced transmission lines on either side of the beam path, which are joined together to share one pair of tuning capacitors connected push-pull. A plan view of the arrangement is shown in Fig. 8. The magnet is built up of 1 inch square ferrite bars stacked as a box with water cooled copper plates separating the boxes. To insure adequate cooling of the ferrite, thermal conducting grease is used between the copper plates and the ferrite boxes, and the whole structure is put under compression. Because of the narrow gap and the length of the splitter magnet, attempts to find a suitable ceramic vacuum chamber for the beam were abandoned, and the whole magnet was placed in a vacuum chamber.

The drive power amplifier for the kicker, which operates at 1/3 the cyclotron rf frequency, has a frequency range of 8.5 to 11.833 MHz and was also



fabricated in house. The magnet was designed to operate at a maximum magnetic field of 42 gauss at 11.833 MHz, which requires a minimum of 3.5 kW of rf power if the ferrite remains cool. A single 4CW10,000A power tube was chosen to drive the transmission line on one side with an equivalent capacitance on the other side. The half-wavelength of the transmission line is approximately 0.84m over the entire operating frequency range because of the tuning capacitors and partial ferrite loading of the tank circuit. The desired frequency range is covered by adjusting the variable tuning capacitors, which have a maximum capacitance of 1000 pf each, from 350 to 760 pf. Ferrite biasing is not used for tuning. The driver for the 4CW10,000A tube is a commercial ENI Model A150 broadband amplifier operating at an estimated 100 watts. A block diagram of the system is shown in Fig. 9. An ALC servo regulates the flux density in the magnet gap, but if the ferrite gets hot, thermal runaway which could damage the expensive material will occur. In addition to the usual water flow and temperature interlocks on the magnet, protective interlocking is also provided by monitoring the plate current of the main power tube, which is

designed to saturate at about 4 kW of rf output. If the plate current becomes greater than required for normal 4 kW operation, the rf drive power is shut off. If this interlock should fail, then the plate and screen power supplies will shut down. Also, a circuit is provided to sense and prevent a voltage imbalance at the capacitor terminals. The detection of a voltage imbalance will similarly shut off the rf drive power.

Full power tests of the kicker magnet off line demonstrated that the Q of the structure dropped slowly at a fixed field amplitude, which led to an increasing rf power consumption and a tendency toward thermal runaway. The permability of the ferrite material changes only slightly with temperature, but the Q of the material exhibits a non-linear reduction as the temperature increases. The Q of the ferrite was also found to decrease slightly with magnetic field. Attempts to chill the cooling water and improve the thermal conductivity between the copper plates and the ferrite were only partially successful. The present status of the magnet, which has not yet been installed in beam line three, is that it will operate stably at about 25 gauss with about 1.5 kW of rf power using a chilled water source. While this is not sufficient to

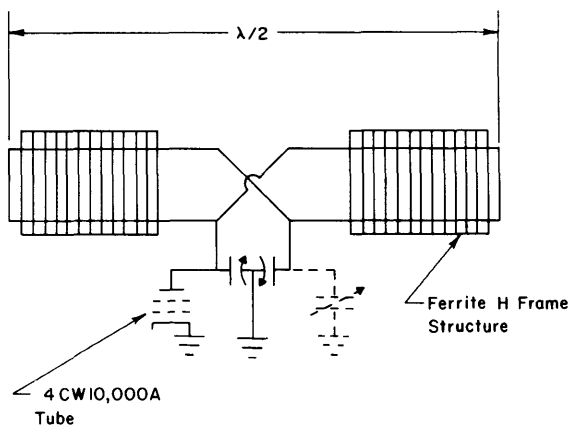
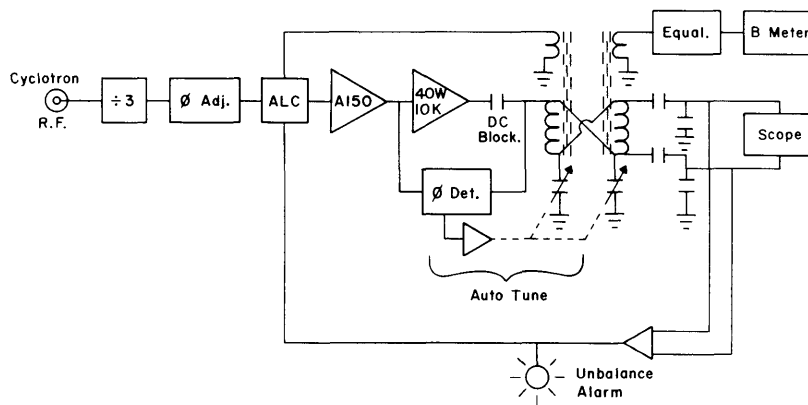


Figure 8. Cross section of the ferrite kicker magnet.



Block Diagram of F/3 Electronics

Figure 9. Block diagram of the beam splitting electronics.

provide the required beam separation continuously for 200 MeV protons, it is enough to begin beam development studies of the beam splitting system at energies up to 80 MeV. The present performance is adequate, however, for the task of filling the Cooler ring with 200 MeV protons, for which it is only required to operate at low duty factor. It may also be useful to the IUCF users to begin split beam operations at the lower energies or at reduced duty factors until a permanent solution to the problem can be made. Hence, plans are underway to install the ferrite splitter magnet in the beam line to begin these beam studies.

- 1) End Effect Corrections in a Short Lambertson Septum Magnet, R.E. Pollock, Proc. 10th Int'l. Conf. on Cyclotrons and their Applications, (East Lansing, MI, April, 1984) F. Marti, Editor, p. 111.
- 2) This report, p. 18.

#### Beam Diagnostics Development

Most of the beam diagnostics presently employed at IUCF are "destructive" monitors which intercept some, if not all of the beam while making a measurement. Although destructive monitors work well in single pass machines and beam lines, these monitors would quickly destroy a circulating beam in a synchrotron or storage ring. For this reason, new nondestructive beam diagnostic systems (which are in common use at laboratories with synchrotrons) are being developed for the IUCF Cooler storage ring. In the past year, three new monitors have been developed and tested in the cyclotron beam lines. Although developed primarily for the Cooler, they can also be very useful in the development and operation of the cyclotrons. These new diagnostics and their applications to the cyclotron and Cooler are discussed below.

#### I. Wall Gap Monitors:

A wall gap monitor can be simply viewed as a single turn 1:1 transformer with the beam acting as the

primary winding and the vacuum chamber as the secondary winding, or perhaps more easily, as a device which forces the wall current (approximately the negative image of the beam current) to flow through an external monitoring resistor<sup>1</sup> (see Fig. 10). The gap capacitance and the EMI shield inductance which parallel the amplifier input impedance must also be considered.

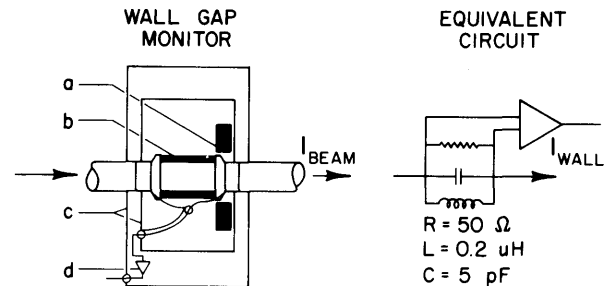


Figure 10. Schematic of the IUCF wall gap monitors, and a simple equivalent circuit which neglects the ferrite core losses. a: ferrite toroid; b: ceramic insulator; c: copper EMI shield; d: low noise wideband preamp.

In the summer of 1983 we received a wall gap monitor as part of an equipment loan from the Fermilab Experimental Electron Cooling Ring. This beam monitor was built as a prototype longitudinal stochastic cooling pickup by the Argonne National Laboratory Accelerator Group. Its usefulness in cyclotron operations and development became immediately apparent after installing it in beam line 2, the beam line connecting the injector and main stage cyclotrons.

Two important properties of these pickups are bandwidth, and susceptibility to rf pickup from sources other than the beam, such as the cyclotron rf systems. The Argonne monitor's bandwidth was measured to be 150 MHz, and the rf noise pickup is equivalent to the signal produced by a 10 to 30 nA beam on the first

harmonic of the cyclotron's rf system, and a 0.3 to 3 nA beam on the second harmonic.

Using the Argonne monitor as a model, we have developed new monitors with bandwidths of 700 to 1200 MHz, and reduced the rf pickup by 35 to 45 db on the first harmonic and 15 to 35 db at the second harmonic, making the rf pickup equivalent to a 200 pA beam on the first harmonic, and a 50 pA beam on the second harmonic. Two of these monitors have been installed in beam line 3 (immediately after the mainstage cyclotron) and another in the swinger beamline.

#### I.1 Uses of the wall gap monitors:

##### a) Monitoring the beam's microscopic time structure:

The most straightforward use of the wall gap monitors is merely to view the amplified signal on an oscilloscope. This gives the operator essentially instantaneous feedback on the beam's time structure, which is very useful in certain situations, such as setting up the pulse selection, tuning up the stripper loop, or doing development work on the  $f_0$  and  $f_0/2$  buncher systems. Figure 11 shows an oscilloscope trace of the signal from the 1200 MHz monitor in beam line 3 for a 24 nA, 120 MeV beam which is pulse selected 1 in 4 (pulse repetition frequency of 7.5 MHz).

##### b) Monitoring the beam's macroscopic time structure:

The normal cyclotron beam current monitors must intercept all of the beam in order to measure the current. In addition, they generally have very low bandwidths to avoid noise from 60 Hz ground loops, etc. Using a double-balanced mixer as a synchronous detector for the signal from the wall gap monitor, we have built a very sensitive, high-bandwidth, nondestructive current monitor. Figure 12 shows an oscilloscope trace of the output of this "Beam Amplitude Modulation Monitor" for a 15 nA proton beam. The 60 Hz amplitude modulation of the beam is very evident, and is being

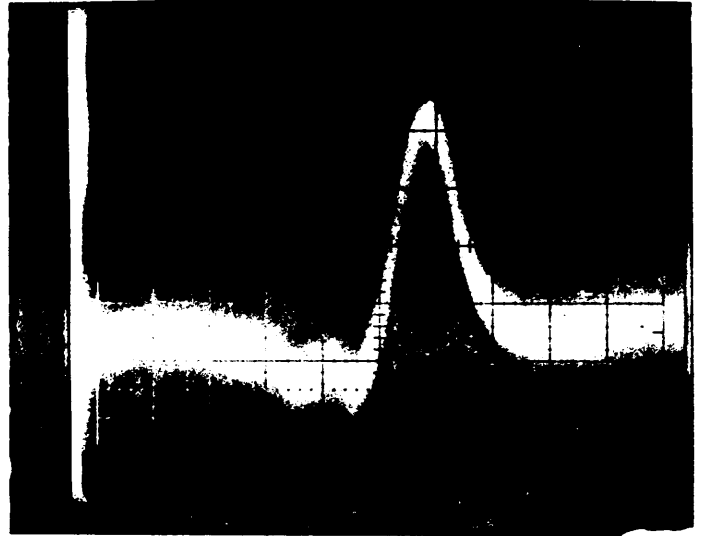


Figure 11. Output of the 1200 MHz wall gap monitor in beam line 3, viewed on a 350 MHz scope, due to the passage of a 1 nsec proton beam pulse of 20,000 particles. (1nsec/div horizontal scale).

investigated using this monitor, as well as other monitors we have built.

c) Beam phase measurement: The construction of a system which uses the wall gap monitor signals to produce a high level rf signal which is phase-locked to the beam is almost complete. The phase-locked rf signals will be sent through isolation transformers and made available to experimentalists to use as triggers for their experiments, and the output of an error amplifier in the circuit which drives the phase shifter can be used as a beam phase monitor.

d) Cooler applications: In the IUCF Cooler, these monitors will be used to monitor many beam properties, such as the bunched beam intensity, lifetime and time structure, and to monitor many other interesting signals, such as longitudinal Schottky signals, and synchrotron oscillation sidebands.



Figure 12. Output of the "Beam Amplitude Monitor" using the beam line 3 wall gap monitor signal for an average beam current of 15nA. (10 nA/div vertical scale; 5 msec/div horizontal scale).

## II. Nondestructive Beam Position Monitors:

Two very different types of nondestructive beam position monitors have been built and tested: one using a microchannel plate detector, and another using split capacitive rf pick up electrodes.

a) Microchannel Plate Detectors: Ions resulting from collisions between the beam and residual gas molecules in the vacuum chamber are accelerated to a microchannel plate which multiplies the charge. This charge is then deposited on a resistive anode encoder. Sensitive current-to-voltage converters measure the current from opposite sides of the anode, and analog electronics calculate the position, and provide feedback for the high voltage power supplies which determine the charge gain of the channel plates. This system was tested in the QDDM line and was able to read the beam position with a precision of a few tenths of a mm with beam currents from 1 to 1000 nA.

b) Split rf Electrodes: Beam position measurements were also made with similar or better precision than achieved with the microchannel plate monitors by using split rf electrodes. The prototype system, tested in

the QDDM beam line, used commercial low noise amplifiers and the spectrum analyzer.

c) Applications: There will be about 40 pairs of rf position electrodes in the Cooler to measure the stored beam's closed orbit and to provide feedback to the rf system during acceleration. Nondestructive position monitors will, in addition, be very useful in the cyclotrons: there are a number of situations where the beam's position must be kept very constant, such as in front of the polarimeters or at target locations, but where a destructive beam position monitor cannot be used because it would cause such a high background.

We are designing our own FET input sum and difference electrode amplifiers. The heterodyne detector system which uses amplitude to phase conversion electronics to determine beam position is based upon the Fermilab TeV 1 system<sup>2</sup>. Once these electronics have been designed, this system will be much simpler and cost effective than the microchannel plate detector system discussed above. A prototype system of this type will be installed in the cyclotron beam lines next year, along with the appropriate software and steering dipoles to test the closed orbit measurement and correction systems for the Cooler.

- 1) R. Littauer, AIP Conf. Proc. No. 105, (1983).
- 2) T. Bagwell et al., Fermilab TM-1254 (May 1984) (unpublished).

## Control Computer

In the second quarter of 1984 the PDP 11/44 replacement for the Sigma-2 control computer was brought to its final configuration of hardware and operating system with the addition of a 70 MB Winchester/floppy disk combination, 0.5 MB of memory (to total 0.75 MB) and installation of RSX-11M-PLUS.

(In fact, in the fourth quarter, a new 11/44 system was received and installed as the new control computer in partial settlement for damages incurred in the 1982 terminal fire. The only affect of this change was to increase total memory to 1 MB. Disposition of the original 11/44 system has yet to be determined).

In the third quarter of the year, on-line testing of the 11/44 was begun during normal cyclotron shutdown periods. Since then all basic readout and control functions have been successfully demonstrated, including status readouts and readout and control of devices in both high voltage ion source terminals and the RF system. The basic set of operator display functions has been expanded to allow seeking of any device to an arbitrary ADC value, invoking a predefined hysteresis cycle, if necessary. Data logging has been implemented, although only a rudimentary facility for displaying logged data has been written. All special readout and control functions (e.g., frequency calibrated dee voltage readout, slit width/position control) have been debugged. Remaining to be tested are some features of the DAC calculation and loading program, a few small programs such as one to report on flowswitch status and control of ion polarization states from data acquisition computers via LINK or DECNET. At present all on-line tests are performed with the entire final hardware configuration of three operator stations; switching between control computers takes a little more than one hour. Progress toward replacement now depends more on cyclotron scheduling difficulties than any other factor.

#### Controls: Existing Facilities

The 64" Scattering Chamber controls suffered erratic position readout breakdown during a number of runs in 1984 before the problem was tracked to encoder

oscillation under vacuum conditions. The two arm position encoders were returned to Litton for new, improved electronics packages. They are now back, and the target encoder has been removed from vacuum. Hopefully this system should soon be back to normal.

A second 16-bit ultra-stable, temperature-regulated DAC has been added to the main magnet power supply. It was resistor-weighted at 7% of the main DAC, to yield a finer current step size than the 20 ma step previously available. Its circuitry is able to accomodate closed-loop control from a future NMR probe.

#### Controls: Dual Spectrometer

The controls system must be expanded to accomodate the needs of the Spectrometer and its beam line. A controls multiplexing station must be installed in the North balcony region and linked to the controls computer. (Planning and construction are now beginning.) A number of controls chassis have already been constructed which will link to this multiplexer: 64 channels of stepping motor drive, 128 ADC channels (50 isolated), 35 DAC channels (isolated), 16 follow-pot channels, 6 water/temp interlock chassis (28 inputs each). Our ongoing effort to incorporate the latest solid state devices into the control system resulted in a number of new designs among the previous list.

Industrial Controllers (in particular the Gould 884) are under evaluation for suitability and price, with vacuum controls in mind.

Two resolver-based position encoding packages have been ordered for the two spectrometer magnet assemblies. Resolvers are mechanically rugged and virtually immune to radiation. Position readout will be available both locally and in the control room, with resolution to 0.01 degrees.