MULTIPLE BEAM OPERATIONS AT IUCF*

D.L. Friesel, T.J.P. Ellison, T. Sloan, and M. Ball

Indiana University Cyclotron Facility
2401 Milo B. Sampson Lane, Bloomington, In. 47408 USA

ABSTRACT

A system for delivering beam extracted from the IUCF k220 main cyclotron simultaneously to several experimental areas was proposed in 1982, was developed, fabricated, and installed from 1984 through 1985, and became operational in 1986. The motivation for this development was to increase the availability of high quality intermediate energy light ion beams for research, but it has also proven to be a valuable aid in the development of new experimental equipment and the commissioning of the recently completed electron cooled storage ring. A detailed description of the beam splitting apparatus in the extraction beam line of the main cyclotron, which consists of a ferrite splitter magnet followed by a septum magnet chicain designed to direct beam to the selected target areas, is presented. Rapid modulation of the klystron buncher phase in sequence with the splitter magnet is used to provide independent intensity adjustment for each user. Some of the advantages, consequences, and practical experiences of providing primary accelerator beams simultaneously to multiple users are also discussed.

INTRODUCTION

The Indiana University Cyclotrons[1] accelerate positive light ions up to an energy of 220 q^2/A MeV, and unlike negative ion cyclotrons such as TRIUMF[2], can deliver only one extracted beam for a given combination of rf frequency and magnetic field. It is operated as a national user facility which provides high resolution beams for intermediate energy nuclear research. The unique energy range and high quality beam capabilities of the IUCF cyclotrons coupled with the one beam/one user limitation contribute to a demand for beam time by experimental users that exceeds our annual capacity by factors of 2 or more. The IUCF cyclotrons are normally scheduled for over 6400 hours of beam operations per year. Experimental equipment and accelerator development activities, like those required for the recently completed k600 high resolution magnetic spectrometer[3] and the electron cooled storage ring[4], cause additional pressures on an already heavily committed accelerator operating schedule. Furthermore, extraction efficiencies from the main cyclotron in excess of 95% are routine and, with some exceptions, available beam intensities exceed the needs of most experimental facilities. These circumstances led to the development of a "beam splitting" system which would allow the simultaneous delivery of beam extracted from the main cyclotron to two experimental areas.

The impact of implementing multiple beam operations at our facility has been considerable, both in terms of the benefits of increased beam availability, and the liabilities of increased laboratory resources required to support two simultaneous users. The design of the splitter hardware, the utilization of the system since becoming operational, and the consequences of implementing this system on laboratory resources are discussed in detail below.

I. IUCF BEAM SPLITTING SYSTEM

A plan view of the IUCF accelerators, extraction beam lines and experimental facilities, including the new Cooler storage ring, is provided in Fig. 1. The location of the beam splitting apparatus immediately following the momentum analysis magnet in the extraction beam line (BL 3) from the main cyclotron is indicated in this figure (area 9). An expanded view of this area showing a schematic diagram of the beam splitting hardware as it now exists is given in Fig. 2. Several beam diagnostic and magnet techniques originally developed to manipulate light ion beams in high energy synchrotron accelerators were used in our design. To accomplish beam splitting, the momentum analyzed beam from the main cyclotron is alternately switched between the high and low field regions of a vertical bending Lambertson[5] septum magnet (L1) by an audio frequency ferrite switching magnet. The switching magnet produces an 8 mm separation of the two beam paths at the entrance to L1 located 3 m downstream for the highest rigidity beams from the cyclotrons. Magnet L1 is place immediately following the image slits of the momentum analysis system, where the beam is at a tight double waist. The beams are further separated and directed to their respective target areas by Lambertson magnets L2 and L3. The beam entering the high field region of magnet L1 (to the left in Fig. 2) is deflected vertically upward through the low field aperture of Lambertson magnet L2, then back down toward the beamline midplane by Lambertson magnet L3, and finally back onto the center of the transfer beam line to target areas 11, 12, 17 or 18 (see Fig. 1) by a conventional vertical steering magnet. The beam switched through the low field region of magnet L1 (beam right) is deflected horizontally either left or right by magnet L2, and passes through one of the low field apertures of magnet L3 on its

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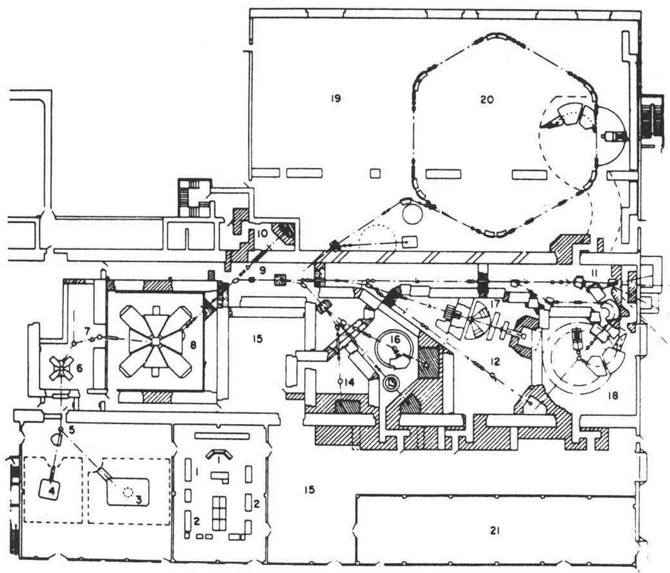

IUCF FACILITIES FLOOR PLAN

1. Control Computer & Console
2. Data Acquisition Area
3. 800 kV Pol. Ion Sourec Terminal
4. 600 kV Ion Source Terminal
5. Stripper Loop Storage Ring
6. Injector (k=15) Cyclotron
7. Main (k=220) Cyclotron
8. Inter-Machine Beam Line
9. Extraction Beam Line and Beam Splitting System
10. High Intensity Hot Cell
11. Neutron Beam Swinger Area
12. Beam Line 5 Target Area
13. 162 cm Scattering Chamber
14. Low-Intensity Area
15. Equipment Setup Area
16. Pion Spectrometer (QQSP)
17. Polarized Neutron Facility
18. K600 Spectromete Area
19. Cooler Building Addition
20. Cooler Storage Ring
21. Mechanicals Area

Figure 1. Layout of the present laboratory facilities showing the location of the Cooler ring, K600 spectrometer, and beam splitting apparatus.

way to the Cooler or to target areas 13, 14, or 16, respectively. Consequently, beam from the cyclotron is actually delivered to the two target stations in a time sharing mode at < 10 kHz rates, as determined by the capabilities of the ferrite switching magnet.

1. Ferrite Switching Magnet

The ferrite switching magnet is constructed of a high frequency ferrite material salvaged from a surplus kicker magnet obtained from the FNAL Experimental Cooler ring[6]. The "H" frame magnet produces an oscillating magnetic field and is excited by 2 coils of 6 turns each driven by a commercial (Kepco) 400 watt bipolar audio frequency op amp power supply. The low power output of this supply limits the rise time of the resulting magnetic fields to about 200 usec. The amplitude of the field at either polarity is independently adjustable between 0 and 60 Gauss to allow for the wide range of cyclotron beam rigidities. The field response of the magnet, which has a continuously variable period from 1 to 40 msec. for each polarity, is shown in Fig. 3. The variable period provides a continuous adjustment of the time averaged beam intensity ratio of the split beams, although the intensity per rf period ('peak' beam intensity) at either target remains equal to that extracted from the cyclotron.

Control of the period and amplitude of the oscillating magnetic field is accomplished through a NIM logic module specifically designed to drive the bipolar power supply. This is but one of many beam diagnostic and control devises developed at IUCF, all of which are discussed in a separate contribution to these proceedings[7]. It permits local operator control of the splitter magnet for sending all the beam extracted from the accelerator to either target area, or to split the beam between the two areas and adjust the ratio of beam sent to each. The splitter magnet can also be controlled remotely through this module by a TTL input from other logic or timing systems. This feature is used to pulse beam from the cyclotrons into the Cooler ring in sequence with the firing of the ring injection bumper or kicker magnets during all Cooler operations. In this operational mode, beam need only be taken away briefly from an ongoing experiment in a cyclotron target area to fill the Cooler ring. Typically, less than 3% of the beam from the cyclotrons is needed to fill the Cooler ring, leaving the remaining 97% available for other users.

2. Lambertson Septum Magnet Design

The 8mm beam seperation caused by the switching magnet must be further increased to permit larger deflections to the various target areas with conventional bending magnets. The rigidity of our beams preclude the use of electrostatic septum devices in the limited beam line space available. Conventional septum magnets[8], which have a relatively thick current-carrying magnetic septum within the gap compared to electrostatic devices, requires high power to operate. The design of the septum magnets L1, L2, and L2 is critical to the efficiency and operational simplicity of setting up beam splitting at IUCF energies. It is necessary to minimize the effective width of the magnetic septum while maximizing the ratio of the deflection angle for beams passing through the high and low field regions. The Lambertson septum magnet, which was developed for high energy synchrotron beam extraction[9], has a vanishingly small physical magnetic septum and does not require high power to operate. Scaling down the Lambertson magnet design to IUCF

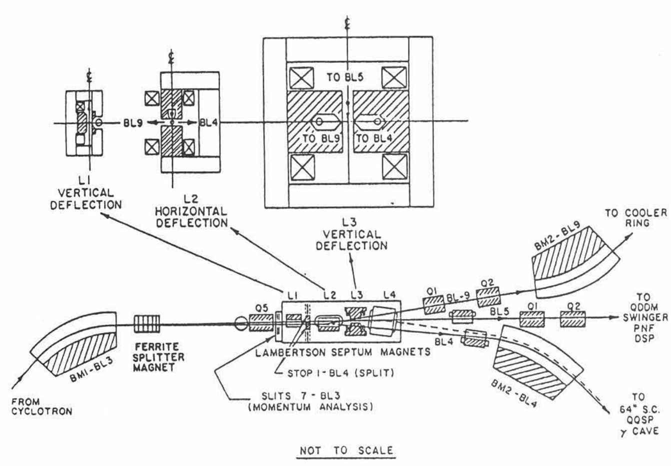

Figure 2. Plan view of the extraction beam line and splitting system.

energies, however, required a careful tailoring of the magnet ends to reduce leakage of the fringe field in the magnet gap into the normally field-free beam path. The basic concepts and the results of a design study for a short septum magnet, which is also used for Cooler injection, were previously reported[10]. Lambertson magnet L1, for example, has a gap of 17 mm and a length of 20 cm. Without end corrections, the integrated fringe field along the beam path in the low field region of a prototype design was about 2% of the gap field. By extending the septum and adding an appropriate field clamp, the corrected magnet has a ratio between the integrated fields along the high and low field paths of about 600 at a gap field of 1 Tesla. This magnet produces up to a 40 mrad. deflection of the beam passing through the magnet gap.

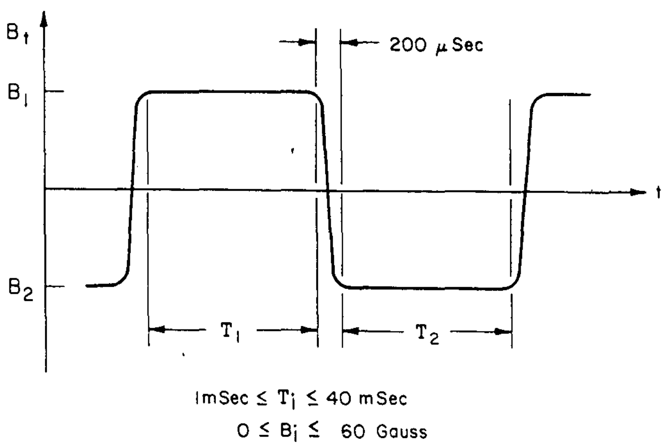

Figure 3. Square wave magnetic field amplitude oscillation of the Ferrite splitter magnet. Both the frequency and amplitude of the oscillation are adjustable.

3. Facility Modifications to Support Beam Splitting

Several modifications to the existing beam handling and radiation safety systems were implemented to facilitate the use of the beam splitting system. Many of the high energy beam line magnetic elements, which shared common power supplies via load switches, required separate supplies so they could be powered simultaneously and adjusted independently. Modifications to the laboratory radiation interlock system were made to allow beam to enter two experimental areas simultaneously, and new radiation interlock stops were installed so that each user could enter his experimental area without disturbing the beam of the other. Another system developed to support beam splitting is a buncher phase modulator, which applies an adjustable square wave phase modulation to the klystron buncher in injection beam line of the cyclotrons. Its purpose is to modulate the beam intensity from the cyclotron in coincidence with the splitter magnet, and thereby vary the 'peak' beam intensity at each target. Details of this system are also described in reference 7. Additional beam current monitoring, target viewing, and charge collection equipment were also developed or acquired to support beam splitting.

II. BEAM DEVELOPMENT AND OPERATION

The splitting system was designed so that when all magnets are turned off, beam passes through them to any of the target areas exactly as it did prior to their installation. Momentum analysis using BM-1 BL3 and the image and object slits in BL 3 & 4 (Figs. 1 & 2) is also done as before, and is performed prior to activating the splitter magnets. Beam development studies demonstrated that the operation of the system was straight forward, with about 98% transmission of beams through the septum magnet chicane to the selected target areas. The 2% loss comes from the 0.2 msec rise time of the oscillating ferrite switching magnetic field, during which time beam is swept across the septum of L1. The beam lost here does not reach the either target area, and the quality of the beam at each target is nearly identical to that achieved when the system is not used. With all beam switched to either target area, there are no measurable beam losses in the splitter system. The tune-up of the beam lines for dual beam operations takes little more time than needed to momentum analyze the extracted beam and to tune each beam line separately. The operator can locally switch all beam to either beam line for individual tuning purposes. When both lines are set up with good transmission, the switching magnet is allowed to oscillate and is adjusted to provide the requested intensity at each target.

The one significant difference in the properties of the split beams is the pulse structure. Because the splitting is done by alternately switching beam from one target room to another, the beam at the target has the cyclotron pulse period (about 30 nsec) superimposed on the switching magnet period. The magnet operates between 0.025 and 1 kHz, hence the 'peak' beam intensity at the target can be up to 40 times larger than the average intensity monitored on the Faraday cup. This is an important consideration for coincidence and other classes of experiments. This problem is minimized by user specification of the allowable split beam ratio and the use of the buncher phase modulator discussed above.

III. SPLIT BEAM UTILIZATION

The use of split beams at IUCF has grown steadily in the 3 years since its installation. At present, approximately 25% of scheduled cyclotron beam operations are run with multiple users. This does not include the mandatory use of the beam splitting apparatus for Cooler ring development, which consumes another 25% of scheduled cyclotron operations. All together then, the splitting hardware is now operating reliably for nearly half of all scheduled beam operations.

To avoid confusion during multiple beam operations, we have found it convenient to classify split beam users as "primary" and "secondary". The primary user specifies the beam properties and allowable split beam ratio, and the secondary user takes as much of the remaining beam as he needs. Split beam usage has been divided about equally between research and experimental equipment development activities. Researchers find it convenient to set up and debug their experimental electronics and detector systems as a secondary user during the run preceding their scheduled primary beam time. Secondary beam is often used to test detector and electronics schemes before primary beam time is scheduled. In this way, users make more efficient use of there approved beam time for experiment. On several occasions, approved experiments have run entirely with split beam as a secondary user.

Perhaps split beam operations have had there biggest impact on the development of new equipment at IUCF. The new K600 spectrometer and focal plane detector system, the focal plane polarimeter system for the spectrometer, the Cooler ring commissioning work, and many other smaller hardware systems have used large amounts of secondary beam during their development. Without beam splitting, the development of these devices could only have been done at the expense of a significant reduction of the scheduled machine operation for experiment.

As development of the Cooler ring brings this accelerator into routine operation for research, it is likely that multiple beam operations will expand to cover nearly all scheduled cyclotron operations. However, the present limitations to continued increases to split beam utilization are the available laboratory resources to man multiple experimental set-ups. The complexity of intermediate energy nuclear experiments has grown considerably in the last several years. Increases in detector, NIM electronics and cable pools are required to equip multiple experimental setups, and there has been a significant increase in the manpower required to maintain or modify experimental facilities in support of the additional users. The cost in manpower and equipment is enormous, and requires a careful management of resources via balancing developmental and experimental priorities. When requests for split beam are denied, it is almost always because of experimental equipment or support conflicts rather than beam or target area incompatibilities.

IV. SUMMARY

We have developed a unique capability of supplying multiple users with beams from the IUCF cyclotrons. The system has been used to increase the research and development activities of the facility, but at a significant cost in additional resources. Nevertheless, the demand for the increased use of this system is expected to grow as the Cooler becomes operational this year.

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