# A DESIGN STUDY FOR SPLIT BEAM OPERATION OF THE INDIANA UNIVERSITY CYCLOTRON FACILITY*

R. E. Pollock, D. L. Friesel and D. W. Devins
Indiana University, Bloomington, Ind. 47401

## ABSTRACT

Some of the design considerations are described for a beam transport system which will permit operation of two experiments concurrently with the external beam of the Indiana University Cyclotron Facility. Beam division by time slicing of the rf pulse microstructure can give widely spaced pulses to a time-of-flight experiment while allowing an experiment not sensitive to the missing pulses to proceed at only slightly reduced intensity and duty factor. Beam division by separation of the horizontal emittance bundle into two parts can give to two users a beam of half intensity with improved quality for high resolution experiments and an unaltered duty factor. The beam line design must be able to act upon the small deflections achieved by electrical separation devices at intermediate energies to produce very different beam paths. A design which will permit operation on split beam mode in the future with no significant increase in the initial capital cost is presented.

## INTRODUCTION

Users of high energy accelerators are accustomed to an operating mode in which several experiments run in parallel. Multiple secondary beams from a single target can be distributed to the several users in a straightforward manner. Multiple extraction systems or beam lines in which the highly penetrating beam passes through several targets in succession can be used to deliver the primary beam to a number of simultaneous experiments. Without the use of multiple beams, the scarcity of suitable facilities would make it even more difficult to satisfy the demands for running time.

In low energy nuclear physics, there is a strong tradition of scheduling experiments in strict time sequence. Each user has undivided use of the entire accelerator facility and its auxiliary equipment for a fixed running period. In general there have been enough low energy accelerators to achieve a reasonable match to the demands for running time by use of the sequential mode of operation. Low energy accelerators provide beams of many particle types. The strong energy dependence of nuclear cross sections leads to the requirement for frequent changes in beam energy. If the probability

* supported by the National Science Foundation

of finding two or more experiments with compatible requirements in energy or particle type is rather low, there is little incentive to attempt to divide the beam among users.

The Indiana University Cyclotron Facility (IUCF) will make available to the physics community a new intermediate energy accelerator which is not easily fitted into either of the above operating regimes. The upper energy limit is below the threshold for production of intense secondary meson beams although the pulsed neutron flux might satisfy more than one user. The primary beam will have very good energy resolution and small emittance which will extend the high precision of low energy experiments to the intermediate energy region. Passage of this beam through a target will degrade its properties significantly so that a system of successive target stations would offer the full beam quality only to the first in line. Multiple extraction is precluded by the design of the accelerator and the laboratory. The high macroscopic duty factor will make possible a wide variety of correlation experiments which will require long running times at beam intensities well below the maximum available. The present low rate of accelerator construction would make it appear unlikely that there will be many more accelerators of this type to share the demands for running time in the near future. With the welcome participation of an active outside user's organization the IUCF may well experience very heavy use within a short time after initial operation. The normal energy range will be high enough that rapid energy variation in the nuclear cross sections will be uncommon. Much of the running time will be devoted to a few light ions. For these reasons a fair proportion of the experiments may well have similar enough beam requirements to be scheduled for parallel operation.

Before the design of the beam transport system which carries the beam from the IUCF final stage cyclotron to the experimental areas was completed, a study was undertaken to establish the feasibility of split beam operation. The intention has been to procure and install beam line components for conventional single beam operation at first. One purpose of the design study was to identify any special requirements in the design of the beam line which would permit a conversion to split-beam operation without major modifications if and when demand for running time warranted the changeover.

## DESCRIPTION

Beam leaves the final stage cyclotron directed toward a hot cell for isotope production. With a bend of $45^{\circ}$, the beam may be directed down one long side of a rectangular experimental area of dimension approximately 20 by 50 meters which has fixed shielding only on the perimeter. By further bends at appropriate locations, the beam can be directed to many possible experimental stations with relatively few arbitrary constraints.

The first $45^{\circ}$ bending magnet is preceded and followed by slits in an arrangement with sufficiently high dispersion to define the beam energy resolution. The horizontal width of the beam as it passes through the $45^\circ$ magnet is limited to 2.5 cm to avoid an undesirable time spread in the short pulses characteristic of the cyclotron rf microstructure. Following the energy analysis, the beam may be directed to independently shielded target areas which house a magnetic spectrograph, a scattering chamber and other experimental apparatus.

In normal single beam operation a bending magnet is energized to divert the beam from one destination to another. If the bending magnet is of the C frame construction an alternative switching action can be obtained by leaving the magnet energized and using a smaller steering magnet at a suitable distance upstream to direct the beam either into the bending magnet or in a slightly different direction which bypasses the bending magnet on the side free of return yoke. The ability to direct the beam to widely divergent locations as a consequence of small changes in beam direction is the central requirement for split-beam operation. Bending magnets with circular pole tips are therefore excluded; however the C magnet is usually the more economical choice because the magnetic field need only cover the region swept out by the beam, which greatly reduces the weight of the magnet.

A design for beam division which required a beam splitting device preceding each branch point in the beam line would be possible (although relatively costly) and would lead to the ability to provide as many simultaneous beams as there were branches. An alternative approach has been selected for consideration, in which a single beam splitting device has been positioned as close to the accelerator as possible. The device divides the beam into two bundles, distinctly separated in horizontal phase space by the application of a transverse electric field. The separation is small enough that both bundles lie within the phase space acceptance of the ion optical components and may be transported as far as necessary to reach the branch point where a major separation is to be accomplished. The two bundles are arranged to recross in the vicinity of quadrupole lenses to minimize aperture requirements and quadrupole steering effects. At each intermediate focal point the beam appears as two well separated rays. A small steering magnet then acts upon one ray to permit the beams to recross again in the next section. At the major branch points a stronger pair of switching magnets are positioned to influence the two rays independently so as to enter or to bypass the large bending magnet.

A sketch of the arrangement is shown in Figure 1. The splitting element has been placed in a long straight section after the first $45^\circ$ magnet. The horizontal beam width at this point is roughly 2 cm, which is large enough that a septum divider will intercept only about 2% of the beam but small enough for a 1 cm gap so that voltages of 50 KV acting over 100 cm length produce ample separations for the highest rigidity beams. With the aid of the horizontally-divergent lens which follows the separator, a separation of 10 cm is achieved at the energy focus near the center of the figure. For simplicity only the first branch point is shown. The switching is achieved by various combinations of bend angle in the two small magnets following

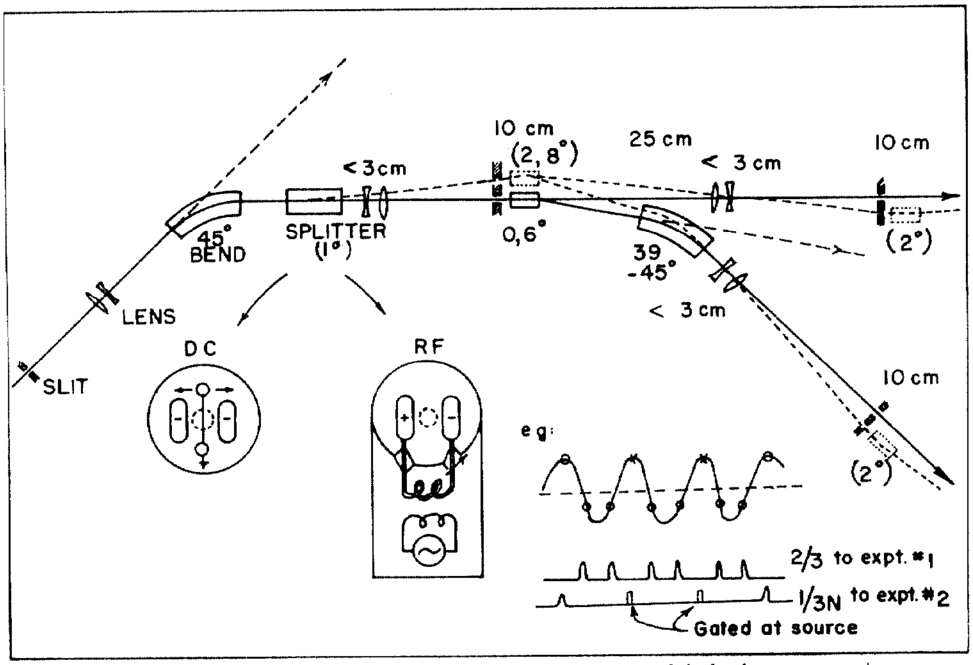


Fig. 1. A section of beam line is shown which incorporates examples of the beam division and switching components. Dotted components are deleted in the initial phase. The inset shows two splitting devices.

the energy slit. For example both beams bypass the $45^o$ bend if the lower of the two small magnets is off ($0^o$) and the upper bends through ($2^o$). With other combinations either beam or both beams may take the $45^o$ bend. The angles and dimensions shown are approximate.

The $45^o$ magnet is designed with a throughport and with a pole tip configuration which will accommodate a range of deflection angles between $39^o$ and $45^o$. In the early stages of single beam operation the magnet sits at the branch point and is turned on and off as required to send beam to one or another target room. When the splitter, dual slit and switching magnets are installed, the bending magnet is simply repositioned as shown in the figure and reduced in strength so that the total bend remains $45^o$ including the effect of the switching magnets. If a single $6^o$ switching magnet is available at the start, even this repositioning is avoided when the splitting hardware is installed.

The scheme is readily extended to a three-way branch with two bending magnets on opposite sides of a straight through line. The switching magnets are then reversible and can divert beam along any two of the three branches.

Two types of splitting device are shown inset in the figure. The DC device consists of a grounded septum with a negatively-charged electrode at each side. The intensity ratio between the divided beams is controlled by a small steering magnet (not shown) near the slit at far left. Buildup of residual activity will be less serious than that within the septum of the cyclotron extraction system. The septum material may simply be replaced periodically. Power densities at the expected intensity level of a few microamperes lead to acceptable heat transfer problems. The experiments sharing a beam split by this device have the same energy and duty factor, independently adjustable intensities and better horizontal emittance than the accelerator beam. These properties are well suited to most correlation experiments and to all high resolution experiments except those limited by available beam intensity.

The rf device has no septum and is bipolar as shown. The details of the resonant line, tuning mechanism and drive amplifier are not shown. The device would operate on a convenient submultiple of the cyclotron rf frequency and would tune over the same 5:4 range. As shown in the figure the transverse electric field alternates sinusoidally at 1/3 the cyclotron rf frequency. Every third pulse is deflected relative to the other two. This example would apply to time-of-flight experiments for which the normal 28-35 MHz beam burst repetition rate is too high. Any experiment in which fast coincidences are not required could make use of the other 2/3 of the beam. By auxiliary beam gating before the injector cyclotron, the time-of-flight pulse separation can be lengthened as required without affecting the second user. Other useful timing patterns may be devised.

## DISCUSSION

Division of beam between two experiments at the IUCF would appear to be feasible from a technical standpoint. Conventional beam line components may be used provided that the bending magnets at beam line branch points are of the economical narrow pole, asymmetric return design rather than multiport switching magnets. The splitting of beams by time separation of the rf microstructure pulses or by division of the horizontal phase space area requires relatively simple devices and moderate transverse electric fields. The only other additional component required is a dual switching magnet which can bend two beams separated by a few cm through independent angles of a few degrees. This magnet may be placed near the vertical and horizontal waists of a point-to-point optical system so that a gap of 1 cm is sufficient. The weight of this component would be well below one ton.

No significant cost penalty has been encountered in design of a beam transport system for the IUCF which will serve single experiments in the first year or two of operation and permit conversion at a later date to dual beam operation without replacement of major components. The cost of the conversion would be expected to be less than 1/2% of the capital cost of the accelerator facility and the increase in available beam time which would result would be expected to be as large as 20% to 40% for the presently envisioned mix of experiments.

Arguments which have been raised against the extra complication of operation in a split-beam mode must be balanced against the prospect for a significant improvement in productivity at relatively low cost.

ACKNOWLEDGMENT

The authors were stimulated to consider the question of split beam operation by some of the arguments raised in an unpublished proposal for an intermediate energy facility by a group of universities ("The Nuclear Consortium") in Southern California. The technical solution advanced in the present work is believed to be completely independent.