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THE MIT-BATES SOUTH HALL RING *

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Abstract

The MIT Bates Linear Accelerator Center is in the process of constructing an electron storage ring. The 190 m ring will be used for internal target experiments with stored beams. It will also be used as a pulse stretcher to provide external beams with high duty factor. The present design incorporates a low beta region with a beta-x of 1 m and a 4.5 m space between ring quadrupoles at the internal target location. The ring will contain up to 80 mA using two turn injection. Extraction using one-half integer resonance will produce up to 50 μA with a duty factor over 80%. Injection will occur at 1 kHz. Design extracted beam properties include an energy spread of 0.04% and emittance as low as 0.01 π mm-mr.

Introduction

The South Hall Ring (SHR) under construction at the MIT-Bates Linear Accelerator Center will provide high duty factor electron beams. There will be stored beams for internal targets and external high duty factor beams. This is the natural culmination of the Bates' developments enabling coincidence experiments in the medium energy range up through 1 GeV. Recently or nearly completed developments, including the recirculator, the polarized source, and the existing set of large spectrometers, position Bates for taking advantage of unique opportunities to address fundamental issues in nuclear science.

The SHR is being constructed to intersect the existing South experimental hall as shown in Fig. 1. With the linear accelerator/recirculator system as the injector, it will produce extracted beams of up to 50 μA with a duty factor of ~85%. Also under construction is an energy compression system which reduces the beam energy spread to ~0.04%. The capability of providing longitudinally polarized beams both externally and for internal target work is included. With two turn injection the ring will store 80 mA for internal target physics. Table 1 summarizes the present Bates' parameters and the expected beam parameters to come from the SHR.

Fig. 1.

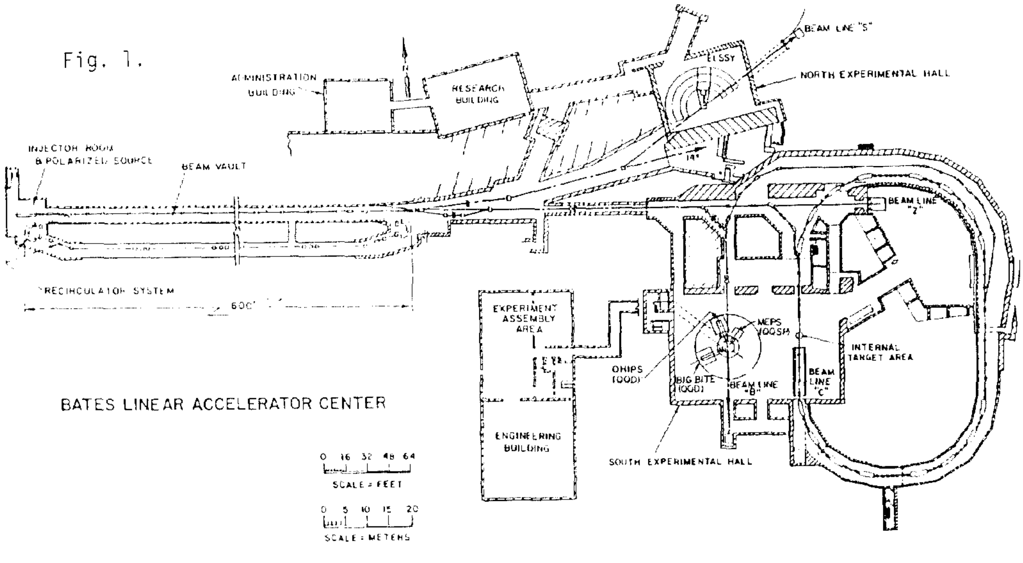

Table 1. Beam Parameters

	Linac Beam SP,SIM,HT	Internal Target Ring Beam	Extracted Ring Beam
Energy (MeV)	50 - 1000	300 - 1000	300 - 1000
Peak I (mA) max.	40, 5, 40	80	0.05
Average I (μA) max.	50	80000	50
Pulse Width (μs) max.	17, 15, 1.3	-	-
Rep Rate (PPS) max.	600,600,1000	1000	1000
Duty (%)	1, 1, 0.13	99	85
dE/E (%)	0.3, 0.04 ECS	0.04 ECS	0.04 ECS

Emittance at 500 MeV

Horiz. (π mm-mr)	0.01	0.01 - 1.0	0.01
Vert. (π mm-mr)	0.01	0.01	0.01

SP = Single pass beam
SIM = Simultaneous recirculation
HT = Head-to-tail recirculation
ECS = With energy compression system

SHR Lattice Design

The ring circumference is dictated both by the constraint that a suitable internal target area exist in the South Hall, and by the pulse length available for injection. The accelerator single pass beam is variable in pulse length up to 17 μsec. However, in order to maximize the peak current to be injected into the ring it is necessary to recirculate the beam in head-to-tail mode where the pulse length will be given by the accelerator/recirculator path length of 1.3 μsec. The 190 m circumference will be suitable for two turn injection. With an accelerated peak current of 40 mA at 1 kHz, this provides a circulating current of 80 mA and an average extracted current of 50 μA.

The SHR lattice functions are shown in Fig. 2. The ring is composed of four basic regions. These include:

1. An achromatic bend region, which is a four cell section forming a second order achromatic.
2. A short straight section connecting two of these bend regions to form a symmetry corrected second order achromatic 180° bend. The result is that it is possible to adjust the ring chromaticity over a wide range without disturbing the symmetry corrected second order centroid shifting aberrations at the extraction and internal target locations.

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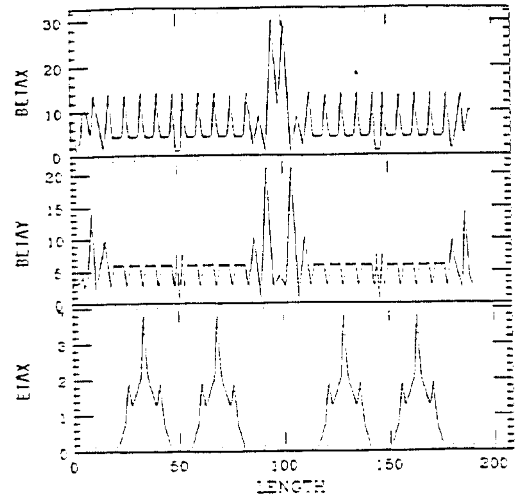
3. The injection/internal target straight section which incorporates a flat beta region for injection and a small beta region for internal target operation. The former is chosen to maximize the displacement of the injected beam from the injection septum and to allow for reasonable strength injection kickers while keeping the septum far enough out of the path of the extracted beam. The latter region is important for maintaining a reasonable lifetime for a stored beam with an internal target. The low beta reduces the angular growth of the beam caused by small angle and multiple scattering in the target.

4. The extraction straight section which incorporates a high beta region to obtain a large displacement of the beam from the closed orbit in order to extract the beam easily. Furthermore, the position tolerances and heating effects on the electrostatic extraction septum are reduced.

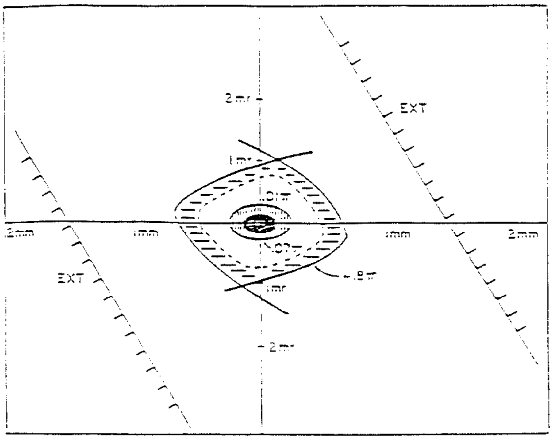
Fig. 2.
FUNCTIONS FOR SOUTH HALL RING



Injection

The recirculator/accelerator pulse (1.3 μsec.) is twice the length of the ring (0.65 μsec.) and therefore up to two turns may be injected into the ring. This can be repeated as often as once every 1 msec. For extraction, the beam is injected with a 3 mm displacement from the septum (and closed orbit). It is possible to inject closer to the closed orbit. Another approach for single turn injection has the closed orbit displaced from the septum and the beam injected on the closed orbit axis. These injection schemes produce a beam at the internal target region as shown by the phase space plot in Fig. 3. The smallest phase space represents the one-turn on-axis injection, while the large annulus is the phase space of the beam occupied for extraction. The intermediate beam area is defined by the minimum space required for the injected beam to cleanly pass by the injection septum during two-turn injection. Note that the beam is always injected on axis in the vertical phase space and is thus a minimum size in the ring.

Fig. 3. Internal Target Beam Phase Space



Extraction

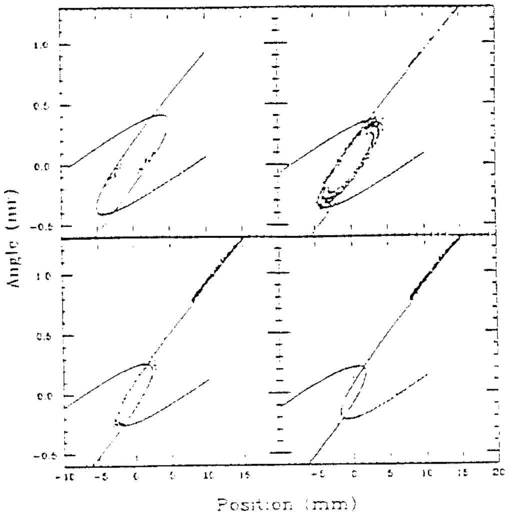
The SHR is designed to provide an extracted beam with a high duty factor, small emittance, small energy spread and high average current. It is important to obtain this with high throughput efficiency and reasonable tolerances. The extraction mechanism employed is that of half-integer resonant extraction. During extraction the horizontal tune of the SHR is adjusted towards a half integer tune with ramping air-core quadrupoles. An octupole operating at a constant strength separates the particle phase space into stable and unstable regions. Initially the beam is injected into the stable region. During extraction the phase space area of the stable region is reduced and the beam enters the unstable region. Its spatial amplitude eventually increases until it passes in the field region of an electrostatic septum where it is directed outside the ring.

Figure 4 shows an example of the extraction process. The intersecting parabolas indicate the theoretical boundaries between the stable and unstable regions of phase space. Each plot represents a successive time interval during the extraction process. The beam inside the stable area is shown as a snapshot during that time interval, whereas the beam outside is accumulated in the figure. After correcting for a correlation in the extracted beam angles as a function of time, the resulting beam emittance is on the order of 0.01 π mm-mr. The time dependence of the intensity of the extracted beam is shown in Fig. 5. The resulting duty factor is 85%.

Internal Target Operation

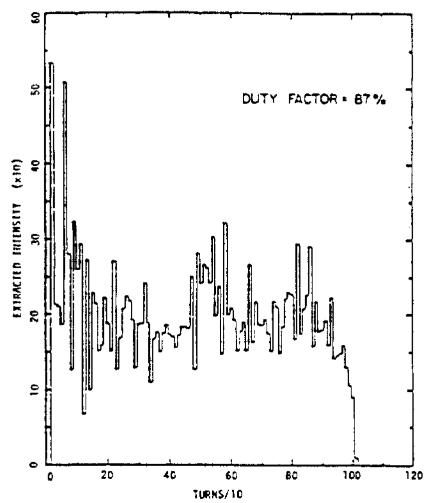
The above description of the injection process indicates the possible stored beam sizes at the internal target location for various methods of injection. The presence of an internal target will affect the nominal beam size. One criteria for the applicability of the ring for use with internal targets is the beam quality, and the time that an adequate beam quality is maintained, with an internal target in the ring. It is useful to consider some of the mechanisms which affect the beam quality and therefore determine the experiments which are feasible. This will also yield information on the

Fig. 4. Extraction Phase Space



possible modes of operation of the ring. The mechanisms include the effects of the target on the beam, the effect of the ring components on the beam and the effects of the beam on the target.

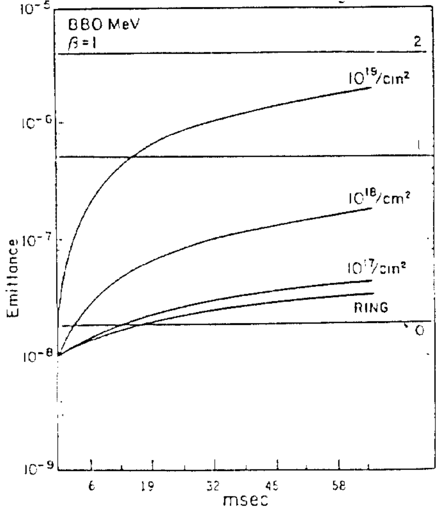
FIG. 5. CHROMATIC EXTRACTION WITH RF



Consideration of the above mechanisms can be used to establish the ring operational limits. For any internal target experiment, the background should be manageable. This will be determined by the beam size, halo and ring apertures. Also, the emittance of the beam must be consistent with the physics requirement for tract reconstruction or resolution.

The emittance growth has been determined as a function of time and internal target density. These calculations were made including the effects of scattering and wakefields produced by target collimator apertures together with the ring damping. Figure 6 shows results for 880 MeV. Also shown in Fig. 6 are several conditions which limit the allowable emittance growth. For example, assuming the use of a non-dispersion matching spectrometer at the internal target, with a focal plane dispersion of 10 cm/%, the beam emittance must be less than 4 π mm-mrad to enable a resolution consistent with the 0.04% energy spread of the beam. (This is called condition 2 in Fig. 6.) In order to minimize backgrounds, the beam emittance must not grow so large as to intercept any apertures which will produce beam spray at the internal target. With the extraction septum, the emittance should be less than 4 π mm-mrad. Without the extraction septum, the emittance should be less than 40 π mm-mrad. In either case, it may be possible to absorb beam spray from these sources. However, if the beam hits the internal target conductance limiting apertures, or a target frame in the case of a self supporting target, it will be difficult to deal with that background. Any thin aperture will produce an effective target thickness of well over 10^5 times that of the target. Clearly, the emittance must be limited to a growth such that the boundary of the beam containing 1.0×10^{-5} of the beam does not intersect the aperture. This upper limit requires an emittance growth to remain below 0.5 π mm-mrad. (This is called condition 1 in Fig. 6.) Finally, if one requires that the emittance not grow by more than 10%, extraction could be carried out while an internal target is in place. (This is called condition 0 in Fig. 6.) With a beta equal to 1 m at the internal target region, all reasonable operating conditions listed above limit the emittance growth of the beam to under 10^{-6} π·m-rad.

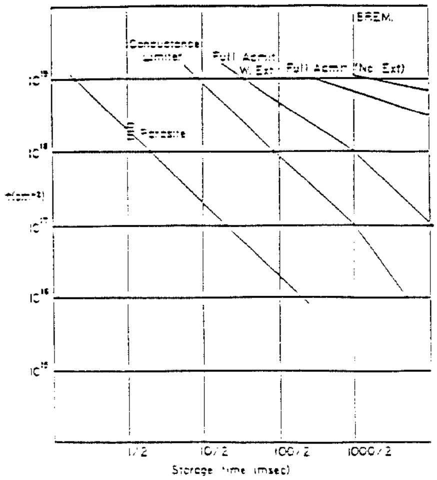
Fig. 6. Beam Lifetime with Internal Target



A fraction of the beam loses energy via bremsstrahlung. That part of the beam which loses more than 20% of the energy is lost near the target. Beam that has lost energy greater than 1% will be lost in the ring. Calculation of this effect gives a contribution to the beam lifetime. If half the beam is lost, the upper line on Fig. 7 indicates the relevant lifetime. The beam lost due to this effect in one second would be equivalent to an average current loss of 0.05 μA.

The horizontal lines on Fig. 6 represent the limits imposed by the constraints discussed above for the different modes of operation. By noting the time it takes to reach those lines, the plot of storage times in Fig. 7 can be formed. The indications are that a wide range of operational modes is possible in the ring. Given the fast refill time possible, targets as thick as 10^{19} cm^{-2} are feasible, and targets as thick as 10^{18} cm^{-2} are possible in a parasitic mode. It is also possible to store beam for many seconds and possibly longer (depending upon ring behavior) with thinner targets.

Fig. 7. Target thickness vs. storage time



Summary

The MIT Bates South Hall Ring will be a powerful and unique tool for nuclear physics. The external beam that will be produced will be comparable to beams from CW machines such as microtrons with its low emittance and small energy spread. The ring will also be used for internal target physics, under which conditions it offers: Large admittance, flexibility (beta functions), high space/element ratio, and excellent beam quality.