TESTS WITH AN ISOCHRONOUS RECIRCULATION SYSTEM

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Introduction

An isochronous recirculation system is in operation at the MIT-Bates Accelerator Center. It is used to transport the electron beam from the output of the LINAC back to the input, to be reinjected so that the electrons pass through the accelerator a second time. The design and the general operation of the recirculation system [1,2] and the Linac [3,4] has been discussed elsewhere. The Linac accelerates electrons to 400 MeV in one pass with a duty factor near 1%, within an energy spread of always less than 0.3% and an emittance of $10\pi/\gamma$ mm-mr. With the recirculation system the accelerator energy capability has been extended to 750 MeV. The accelerator is designed with a progressive series of stop bands to prevent the propagation of transverse modes, thus raising the calculated threshold of beam break-up (BBU) to more than an order of magnitude above operation needs for both single pass and recirculated operation. The recirculation transport system (RTS) is isochronous and highly achromatic allowing for an energy band pass of 6% in which the beam is fully transmitted through the accelerator twice. The admittance of the accelerator is about 0.3πmm-mrad for the recirculated beam.

In this paper we will describe, qualitatively, observations of the operation of the recirculation system under a variety of conditions. In particular, both simultaneous and head-to-tail recirculation have been accomplished. The former was done under a variety of phasing conditions of the second pass beam relative to the first. The instrumentation used in the evaluation of the tests include a beam current monitor (toroid) which measures the peak current, and the Rf loads of the output of the traveling wave waveguides which measure effectively the product of the current in the waveguide and the energy gain in that section of waveguide.

Simultaneous Recirculation

The recirculation system is normally operated under the conditions of simultaneous recirculation. In this case, the pulse length of the beam injected into the Linac is longer that the sum of the path lengths of the RTS and the accelerator. Under these conditions, there is a period of time during which the peak current in the accelerator is doubled. A purpose of this method is to maintain the normal beam pulse length and thereby preserve the duty factor. The effect of the additional beam loading, decreases the energy of the first pass beam. However, this beam must continue to be transported through the RTS and the accelerator for a second pass. This is important in determining the energy band pass necessary for operation of the recirculation system. The phase of the second pass beam relative to the accelerator Rf is controled by the path length through the RTS by moving the 180 degree dipoles at each end of the system. The magnetic element layout is shown in Figure 1.

Foward Phased Simultaneous Recirculation

In typical operation, it is desired that the second pass beam gain the maximum energy and that the final energy spread be minimized. The latter describes the reason for the need of an isochronous system. Therefore, the RTS path length is an integral number of Rf wave lengths and the beam is reinjected near crest. The maximum peak current that is possible to recirculate without any corrections is given by the energy band pass. Figure 2 shows 7mA peak current

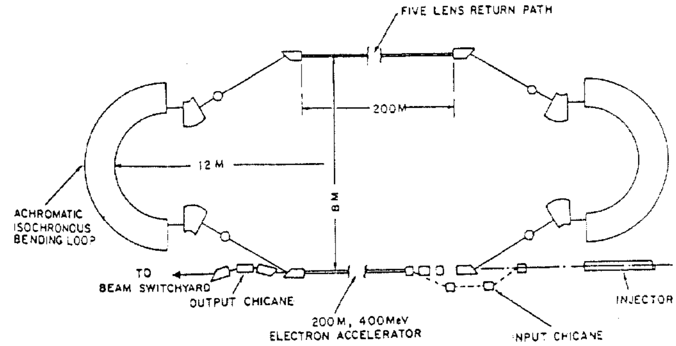

Fig. 1. The components of the Recirculation System

recirculated from 250 MeV to 480 MeV which requires a 6% energy band pass. Note the step on the leading edge of the second pass beam resulting from the time required to travel the system path length before the second pass beam is reinjected. It is also possible to shift the phase of a klystron Rf source during the time when the second pass beam is reentering the accelerator and increase the energy gain, thus compensating for the additional beam loading. In Figure 3, the toroid trace at the end of the accelerator is shown for the case when compensation was used to recirculate 11mA to 480 MeV. Over 35μA average beam current at energies over 750 MeV have been supplied for nuclear physics experiments.

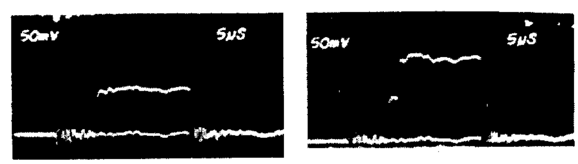

Fig. 2. Left hand photo is 7mA first pass beam in Linac Right hand photo is same toroid during simultaneous recirculation.

Fig. 3. Simultaneous Recirculation of 11mA peak current using phase shift compensation

Cross-Phased Simultaneous Recirculation

As a demonstration of the ease of phase control and a test of the effect of the phase control method on the beam optics, the recirculator transport system was lengthened by 90^0 (2.63cm). In this case, the second pass beam did not gain energy, but the beam was transmitted through the accelerator. Having gained no energy, it reentered the RTS and was reinjected through the accelerator a third time as shown in the toroid output in Figure 4. The third pass transmission was reduced due to the additional energy spread of the beam as a result of its cross phased condition through the Linac during the second traversal.

Back-Phased Simultaneous Recirculation

Another phasing condition tested involved lengthening the path length of the RTS by 180^0 (5.25cm). In this case the beam was deccelerated and energy is given back to the accelerator. This mechanism should lower

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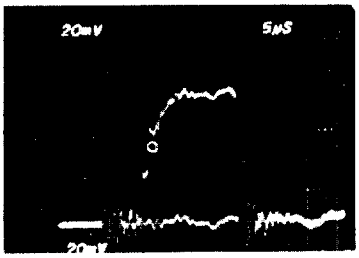

Fig. 4. Cross-Phased Recirculation. Note the two steps indicating three traversals through the Linac

the threshold for BBU and enhance the chance to detect that phenomena. In addition, this method of energy recovery, although not significant for our relatively lightly loaded conditions compared to the input Rf power, can be useful in cases where much higher currents are used such as in free electron laser systems [5].

Figure 5 shows the Rf load during a typical foward phased condition. In this case the section is not powered and the beam induced the Rf signal. Figure 6 shows the Rf load during the back-phased condition. Note the reduction of the induced Rf after the second pass beam has reentered the waveguide. Figure 7 shows the toroid signal at the end of the Linac indicating that full transmission with no signs of pulse shortening of other instabilities is achieved. It was difficult to maintain full transmission at exactly 180^0 back phased due to the accelerator focussing, which consists of six widely spaced doublets within 200 Meters. Full transmission was achieved up to within a few degrees of 180^0 or a final beam energy near 23 MeV. (Note that 20MeV comes from the injector and cannot be taken out.)

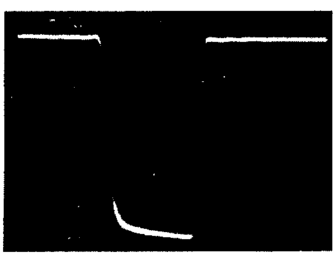

Fig. 5. Beam induced signal at an Rf load during Foward Phased Simultaneous Recirculation

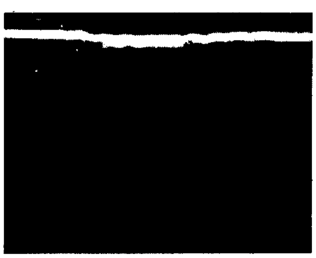

Fig. 6. Beam induced signal at an Rf load during Back-Phased Simultaneous Recirculation

Fig. 7. Toroid signal at end of Linac during Back-Phased Simultaneous Recirculation

Head-to-Tail Recirculation

Another mode of recirculation uses a shorter pulse length, such that the pulse length from the injector is equal to the sum of the path lengths of the RTS and the Linac. In this way there is no additional beam loading in the Linac from the second pass beam and no peak current limits thereby. In principle, higher peak currents can be accelerated than with the simultaneous recirculation method. This mode of operation is useful, for example, for injection into a pulse stretcher ring [6], where short, high intensity pulses help to minimize the number of turns needed for injection and achieve a desired high intensity output current.

The limiting conditions in this case are constraints placed on the final recirculated beam energy spread. The transmission of the second pass beam must be very close to that of the first pass beam. If not, then the accelerator loading will adjust to the difference in peak currents during a filling time. At the MIT-Bates Linac, the longest filling time is 1.3μsec while the Head-to-Tail pulse length is 1.3μsec. Therefore the energy of the second pass beam will vary over the entire length of the second pass beam if the second pass peak current is not very close to that of the first pass peak current. It should be noted, that in the case of the first pass beam, an additional 1.3μsec is injected in anticipation of the initial beam loading transient which is lost on a water cooled slit at the entrance to the RTS.

Single Pulse Head-to-Tail Recirculation

We have recirculated 40mA of peak current in the head-to-tail mode of operation as shown in Figures 8 and 9. Full transmission of the second pass beam was obtained to within the accuracy of reading the toroid signal trace (1-2%). However the full energy spread of the beam was contained within 0.6% rather than the normal 0.3%. There are several possible explanations for the additional energy spread. More tests are planned to understand these effects.

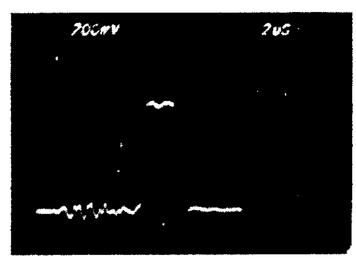

Fig. 8. First pass beam injected for head-to-tail Recirculation of 40mA peak current

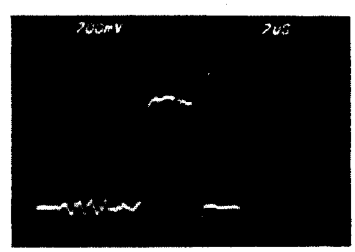

Fig. 9. First pass beam followed by second pass beam during head-to-tail recirculation of 40mA.

Head-to-Tail Pulse Train

Given the fact that we have over 20μsec of Rf available for use, it is possible to recirculate more pulses in the head-to-tail mode. Once the initial beam loading transient is taken care of and a recirculated beam passes through the accelerator, a new 1.3μsec beam from the injector can be injected behind that last recirculated pulse. This process can continue until the Rf is filled with beam. Then, from the point of view of the Linac, there is a continuous beam, while in reality, it is a succession of head-to-tail pulses, and a discrete set of pulses 1.3μsec long separated by 1.3μsec are output. It would be possible to use this method for multiturn injection into a pulse stretcher ring.

This mode of operation was tried with the results shown by the toroid traces shown in Figure 10. The transmission was limited for this test by a misalignment in the accelerator which reduced the admittance. A pulse train consisting of three pulses of 20mA was successfully accelerated. However, although the first and the third pulses had energy spreads containable within 1%, the second pulse was not stable and not consistently transmitted through an energy defining aperture of 1%. Whether this instability was due to the transmission, or effects of timing between the pulses has yet to be determined.

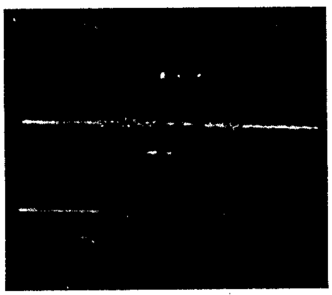

Fig. 10. Head-to-Tail Recirculated Pulse Train. Lower trace shows pulse train in accelerator. Upper trace shows output pulses.

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