SPECTROMETER CHOPPER FOR AHF AND SSC LOW-ENERGY TRANSPORTS*

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Abstract

Presented is the study of a possible chopping system for the advanced hadron facility and the Superconducting Super Collider. A 200-MHz RFQ may be preferable to lower frequency structures for the injection linacs of AHF and SSC. To achieve a pulse frequency of 50 MHz, a chopper must be developed to eliminate three out of four bunches at the tenth of a percent level. Conventional choppers suffer from rise time limitations due to the finite separation of the deflecting plates. One alternative is a spectrometer chopper which modulates the energy of each bunch and then separates the bunches with a spectrometer transport. Initial design studies are presented for this concept.

Introduction

The low-energy injectors for modern accelerators usually consist of an ion source, a Radio Frequency Quadrupole accelerator (RFQ), and a conventional accelerator (drift tube or coupled cavity). This system accelerates the ion beam to energies of several hundred MeV for injection into higher energy, circular accelerator systems. The low-energy injection process is critical in determining the overall phase-space distribution of the beam and in setting up the time structure of the beam.

One of the major objectives in the design of the low-energy accelerator system is to limit the emittance growth, the tails, and halos of the beam. In addition to emittance growth considerations, designs of the low-energy injection accelerator must incorporate systems to tailor the beam both transversely and longitudinally. Losses for high average current beams must be limited to reduce activation levels and radiation damage along the accelerator. It is also desirable to introduce the needed time structure on the beam while the beam is at energies less than a few MeV. Such tailoring systems usually consist of adjustable apertures and deflectors to select and scrape off the unwanted portion of beam.

Proposals for the advanced hadron facility[1] and the SSC[2] call for a 50-MHz micro-structure beam to be injected into the booster at the end of the linac. Studies indicate[3] that the desired longitudinal emittance can be achieved by initially bunching and accelerating the beam with an RFQ run at frequencies of 150 MHz or greater. This imparts a structure of the same frequency on the beam; therefore a chopper must be included in the low- energy segment of the accelerator to eliminate the unwanted micro-pulses, leaving a 50-MHz micro-structure. One such chopper proposed[3] is an rf deflector to transversely sweep the unwanted bunches out of the beam. This scheme could lead to some additional transverse emittance growth as the beam is being swept over transverse phase space during the micro-pulse.

Spectrometer Chopper

An alternative approach to an rf deflector is to sweep the beam longitudinally with a 50-MHz rf cavity. The time-dependent energy variation of the beam is then coupled to a transverse deflection of the beam by use of a bending magnet as a spectrometer. The unwanted micro-pulses are removed on an aperture as the beam sweeps across the transverse plane. To reduce the transverse emittance growth introduced by this process, the longitudinal-transverse coupling is then eliminated with a second bend. The "spectrometer chopper" system described above is illustrated in Figure 1. Using this system might reduce the transverse emittance growth introduced by a conventional rf deflector system, but at the expense of additional longitudinal emittance growth. Such a transport system has been studied and is feasible, though it may not be an optimal solution for all applications. The tradeoff between longitudinal and transverse emittance growth must be studied more carefully and the best alternative determined for the particular application.

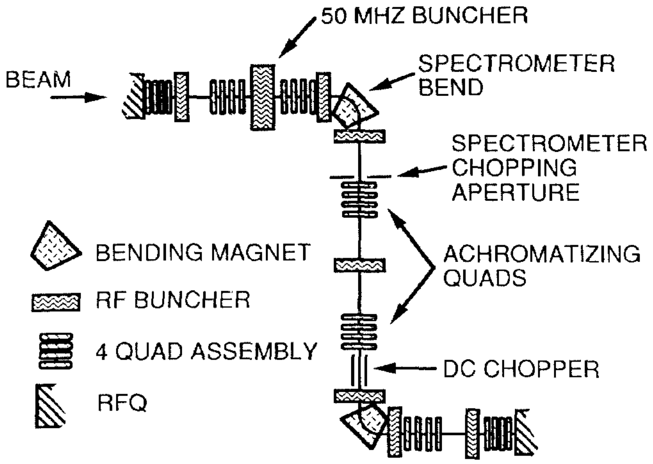

Fig. 1 Layout of spectrometer chopper transport. Total path length 17 meters.

There are several constraints on the spectrometer chopper transport design. First it must have a buncher and spectrometer system to separate the unwanted pulses. The transport should be achromatic to minimize the effects of the buncher on the emittance of the beam. The spot size of the beam at the chopping aperture must be sufficiently large so as not to melt the chopping aperture. The beam must be matched both longitudinally and transversely to the downstream accelerator. This implies that several additional bunchers are needed to maintain the longitudinal bunch structure of the beam as it passes through the transport.

The general beam parameters relevant to this study are presented in table 1. Based on general design studies,[4] the upstream RFQ, between the source and transport, is chosen to run at 200 MHz and to accelerate to 1 MeV. One advantage

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Table 1. Input Beam Parameters Used for Transport Design

Energy	1 MeV
Particles per Bunch	4×10^{8} protons
Twiss Parameters and Emittance	
α_x	-1.1
α_y	1.1
β_x, β_y	4.5 cm/mrad
$\varepsilon_x, \varepsilon_y$	$0.2\,\pi$ cm mrad, rms unnormalized
α_z	-0.19
β_z	11.6 ns/MeV
ε_z	$9.7\times10^{-3}\pi$ ns MeV, full unnormalized

of using 1 MeV as opposed to a higher-energy beam is that it minimizes the power of the deflected beam on the aperture. The advanced hadron facility has beam pulses 1 msec long at peak currents of 22 mA. The energy contained in one beam pulse at 1 MeV is 22 Joules. When such a beam pulse is deflected onto an aperture, there is little time for the heat generated to dissipate through the material of the aperture. The beam size must be kept sufficiently large to reduce the beam power density, such that a single beam pulse will not melt the aperture. Studies and experience indicate that a 1-MeV beam with root mean square radius greater than about 0.5 cm will not melt a thin, water-cooled, pyrolytic-graphite aperture. It should be noted that this constraint on spot size does not apply to the SSC which has beam pulse length of only 37 us.

The upstream RFQ delivers a beam with a 200-MHz micro-structure. A 50-MHz micro-structure is desired. A 50-MHz rf buncher is used to to accelerate one out of every four bunches such that they are accepted through the spectrometer. This concept is illustrated in Figure 2.

In addition to the 50-MHz rf structure, several 200-MHz bunchers are needed to maintain the micro-structure of the beam through the transport. To avoid longitudinal emittance growth, the longitudinal extent of the beam should be kept within about a half cycle of the 200-MHz rf. Even within this constraint, the effect of the bunchers is highly non-linear. To model the longitudinal motion of the beam, a simple tracking code was developed to integrate particles though the transport structure. The input distribution, the beam pulses as separated in energy space by the 50-MHz buncher, and the resulting output distribution are shown in Figure 3. Less emittance growth can be achieved with closer-spaced bunchers, but room is also needed between bunchers for focusing and bending elements.

The transverse optics of the transport are studied with the code TRACE. This code calculates the envelope of the beam using a Gaussian optics approximation and it includes the effects of space charge to first order. Figure 4 shows the transverse envelope of the beam through the transport. The first bender of the transport is used as the spectrometer. The dispersion of the transport at the chopping aperture is 3 cm/%Δp/p. Peak gap voltages of 17 5 kV are needed across each of two gaps in the 50-MHz buncher to separate the bunches by 5.2 cm at the aperture. The half-widths for 98 percent of the beam, including the effects of dispersion, are 1.3 cm for the on energy pulse and 5.2 cm for its neighbors. To reduce the effects of dispersion, a symmetric design is used with the eight quadrupoles between the bending magnets used to achromatize the tune. The last four quadrupoles in the transport are used to match the beam to the downstream RFQ.

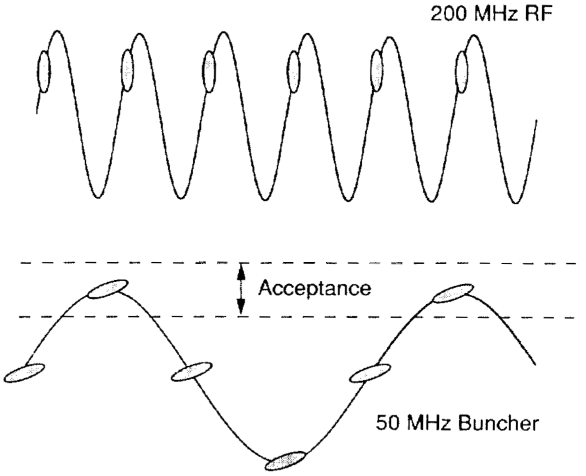

Fig. 2 Representation of "spectrometer chopper" transport. Beam from the upstream RFQ has intial micro-structure of 200 MHz. The low-frequency buncher in the transport runs at 50 MHz, accelerating each beam bunch as indicated above. A bending magnet separates the bunches and the unwanted bunches are scraped off on slits. The remaining beam has a 50-MHz micro-structure and is injected into the next accelerator.

In addition to a fast deflector as described above, it is desirable to include a conventional deflector to eliminate additional micro-pulses. The deflector needs an effective rise time of 19 ns. There is sufficient space to add a conventional, traveling-wave deflector between the two bending magnets. For a plate separation of 6.0 cm and a length of 100 cm, 1.8 kV is needed on each plate to fully deflect the beam. A 6-cm plate separation also implies that a minimum rise time of 5 ns can be obtained, which is well within the desired value.

Conclusion

The use of a 50-MHz rf bunching structure and a spectrometer provide an alternative method for fast chopping of low-energy ion beams. To minimize emittance growth in high current accelerators, it is desirable to begin the acceleration process immediately after the ion source and to use as high an rf frequency as possible. At energies of 1 - 2 MeV it is often desirable to introduce a transport section to tailor the beam before further injection. Micro-pulse separation can be obtained with an rf structure which differentially accelerates micro-pulses and then separates them transversely with a spectrometer. The above study shows the feasibility of such a structure for use in the advanced hadron facility and possibly SSC. Detailed studies of this design with codes such as SCHAR[5] still need to be performed to determine the emittance growth. These results must be compared with alternative chopper schemes to determine the optimal solution.

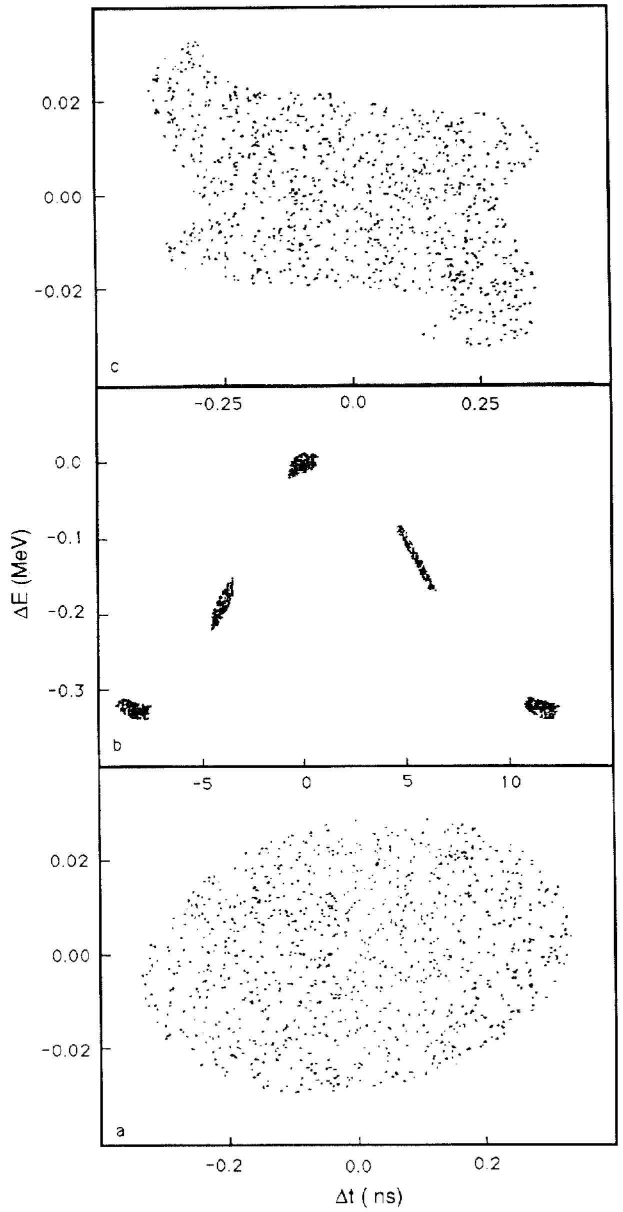

Fig. 3 Results of longitudinal tracking a) input distribution, 1000 particles, $\varepsilon/\pi=2.4\times10^{-3}$ MeV ns. b) five bunches after 50 MHz buncher, 200 particles in each bunch. c) distribution of central bunch at the end of the transport, $\varepsilon/\pi=2.7\times10^{-3}$ MeV ns.

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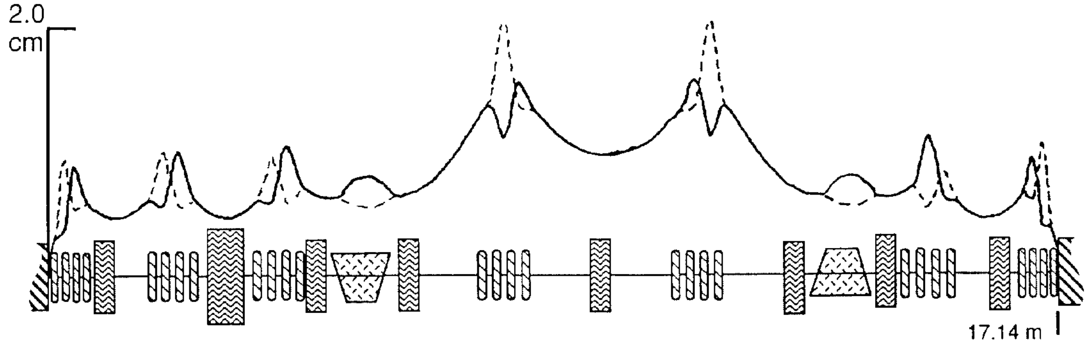

Fig. 4 Results of TRACE calculations, including space charge; horizontal —— and vertical – – envelopes for 98% of the beam.