FUNNEL SECTION FOR THE APDF UNDER VARIOUS ERROR CONDITIONS *

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Abstract

The proposed Accelerator Performance Demonstration Facility (APDF) [1] calls for two separate low β sections, each comprising of an ion source, a Radio Frequency Quadrupole (RFQ) and a 350 MHz drift tube linac (DTL). Each of the sections delivers 100 mA, CW, H^+ beam at 20 MeV. The two beams are then merged together in the funnel [2] section to form a collinear beam of 200 mA. The simulated performance of this funnel section in terms of the funnel-output beam characteristics under various input beam error conditions, component misalignments, and operational errors is described in this paper.

Introduction

In recent years, several high-power linear proton accelerator designs have been proposed from Los Alamos. These designs are aimed at various applications, collectively known as Accelerator Driven Transmutation Technologies (ADTT) [3]. Most of these accelerator designs have one key component in common. That component is a funnel where beams from two separate but identical front end linac systems are merged to form a collinear beam of twice the initial beam intensity. In the proposed APDF which is the front-end prototype of the first 40-MeV of the APT [4] accelerator, beams from two ion sources are fed into two separate RFQ/DTL combinations operating at 350 MHz. The output at 20 MeV from each of the DTLs is then funneled to a single high energy linac operating at 700 MHz which accelerates the beam to 40 MeV.

Details of the conceptual design i.e. physics design, rf and engineering designs of the key components, and simulation results are contained in Refs. 4-6. Here we report only on the results of the error studies made on the funnel section.

The layout of the components is shown in Fig. 1. Each leg of the transport region consists of eight electromagnetic quadrupoles (EMQs) and two conventional two-gap 700 MHz bunchers (R3 and R2). These elements transport the beam with about the same transverse and longitudinal focusing strengths as in the exit of the DTL. The funnel legs are designed with 700 MHz bunchers operating at the second harmonic of the beam, resulting in smaller cavities and saving of power and space in a fairly tight configuration. The second of the two buncher cavities (R2) has a special tapered geometry to enable the bunchers in the two adjacent legs fit together. The last two quadrupoles in each leg are permanent magnet quadrupoles (PMQs) for compactness, while the final quadrupole in the merge section just upstream of the deflector cavity is a large-bore EMQ wherein both beams enter off-axis. The dipoles in each leg bend the beam by 9.77° each , while the common large bore EMQ steers the beam ~ 1°. The rf deflector cavity provides the final ~ 2° of bend to merge the beams on axis. The funnel parameters are given in Ref. 4.

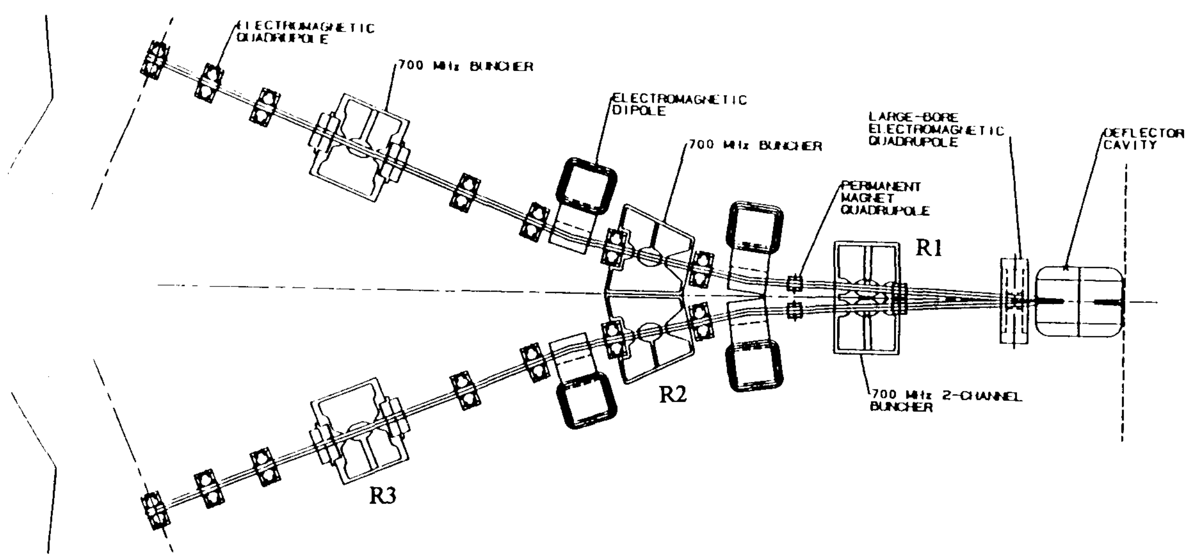

Fig.1. Layout of the components for the APDF funnel

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Error Study

Error simulation studies were done with a matched uniform 3D input distribution of 10K macroparticles. For comparison, a reference run without any error conditions was done. Output phase space plots for this are shown in Fig. 2. Relatively large numbers of macroparticles were used in order to limit the statistical variation from run to run within ± 1%. The code FUNNEL2D, a modified version of PARMILA was used. For computation-speed, 2D space charge routine was used once it was established that 3D and 2D space charge calculations produced essentially same results. Four types of error conditions were examined : 1) buncher errors, 2) input beam errors, 3) quadrupole errors, and 4) deflector errors.

Buncher Errors

The individual buncher phases were varied by ± 5.0° from the nominal operating phase of -90°, while the rf field amplitudes were varied by 5-10 % from the nominal operating values required for I=100 mA longitudinal matched conditions. All the bunchers were subjected to the error conditions concurrently. The output beam Twiss parameters were found to be insensitive to errors of such magnitudes. Since in reality, the bunchers will have both phase and amplitude errors, simulations were performed with all the bunchers subjected to a phase error of ± 2.5° and an amplitude error of ± 5 % simultaneously. The output phase space distributions shown in Fig. 3, are essentially the same as in Fig. 2. Both the transverse and longitudinal emittances were essentially the same as in the reference run. The output Twiss parameter variations were at the level of 10-15 %. The energy and phase centroids showed modest shifts. In actual operating conditions, the buncher relative phases and amplitudes could be controlled within ± 1.0° and 1-2 % respectively.

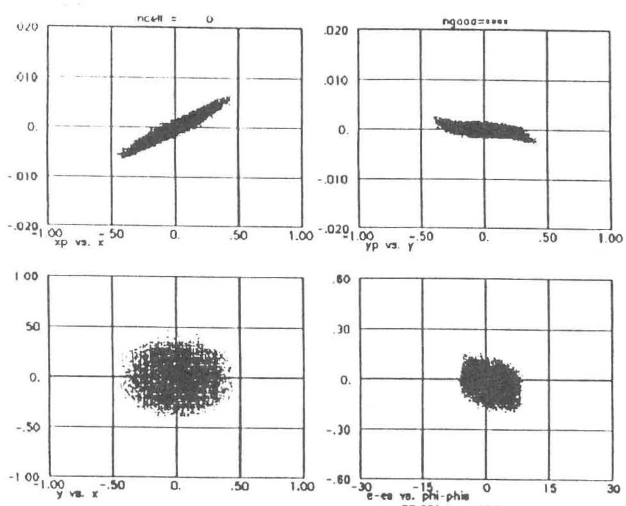

Fig. 2. Output phase space plots without any error conditions

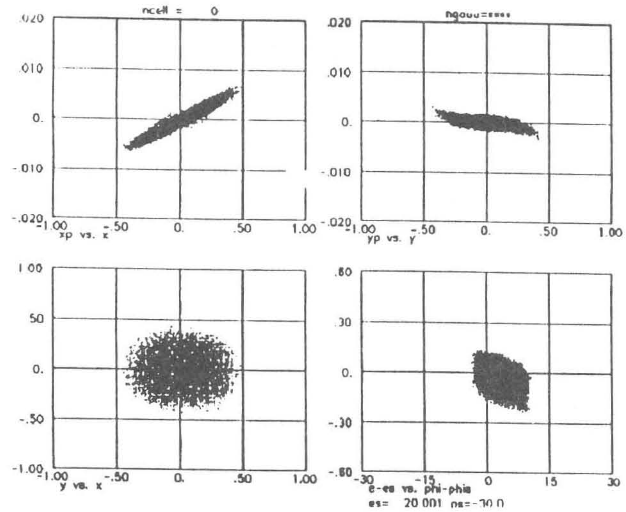

Fig. 3. Output phase space plots with buncher errors

Above simulations show that such level of control is more than adequate from beam dynamics point of view.

Input Beam Errors

The effects of input beam misalignments were studied in some detail. There could be several types of errors associated with the beam entering the funnel section. These are: 1) transverse (x,y) displacement errors, 2) input angle errors, and 3) input beam phase and energy errors. The effects of these errors were studied independently as well as in combination.

To start with, the input beam was displaced in both x and y separately to set an upper limit for an acceptable beam at the output end of the funnel. The figure of merit for "acceptable" beam was: a) no loss of particles and b) very small or no additional increase in emittance. Simulations show that the input beam could be displaced by as much as ~3 mm before one sees additional emittance increase or particle loss. Using the same criteria, input angle limits were found to be ~4.5 mrad. However, these limits are relevant when the error in each dimension is considered separately. In reality, errors will be associated with each of the parameters, i.e. x, x′, y, and y′. So, simulations were done with various combination of beam offsets selected from $\Delta x = \pm 1$ mm, $\Delta x' = \pm 1$ mrad, $\Delta y = \pm 1$ mm, and $\Delta y' = \pm 1$ mrad. In the most affected output, centroid is shifted by ~1.4 mm in x, ~3.0 mm in y. The corresponding x′ and y′ offsets were ~3.8 mrad and ~3.0 mrad respectively. This illustrates that large input beam position and angle errors will require steering corrections.

To study the effect of offset in the longitudinal parameters of the input beam, we varied the phase and energy by ± 0 - 5° and ± 0 - 100 keV respectively. There was no additional increase in the emittance. A five degree offset in phase alone produces an output centroid shift of ~3° in phase and ~60 keV in energy. Similarly, energy offset of 100 keV in input energy results in a phase shift of ~1.4° and ~60 keV in energy. Input errors in both the parameters, i.e. 5° and 100 keV in phase and energy result in an output centroid shift of ~6° in phase and ~140 keV in energy respectively. Finally, we did simulations with input beam errors in all the six dimensions effective simultaneously. The results affirm that for typical errors in the input beam, there is no additional growth in emittance or loss of particles.

Quadrupole Errors

The beam dynamics simulations were done for random quadrupole alignment errors. Three different types of alignment errors were considered: 1) Transverse displacement errors 2) tilt errors, and 3) rotational (roll) errors. The errors were allowed to vary randomly as a uniform distribution within the following range of values: ± 5 mil in the transverse x or y dimension, ± 0.25° in tilt, and ± 0.25° in roll. All three types of error conditions were operative on each quad.

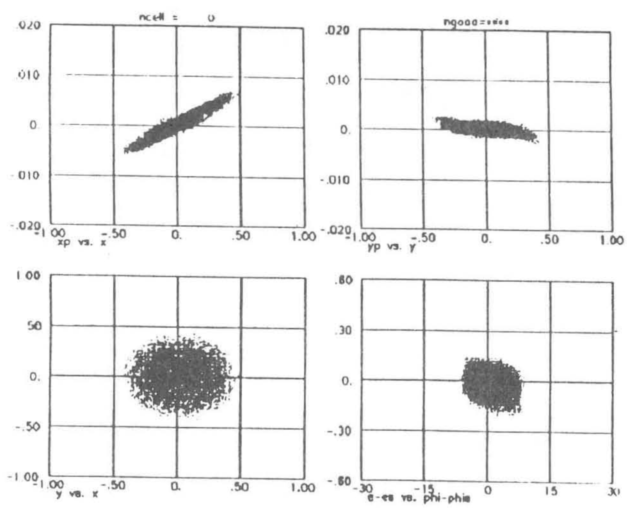

Fig. 4. Output phase space plots with quad error conditions

All the quads were subjected to error conditions concurrently. The output phase space plots are shown in Fig. 4. Errors of such magnitudes in the quad alignment do not show any additional emittance growth or significant excursion of the beam centroid compared to the reference run. In practice, such alignment tolerances are easily attainable.

Deflector Errors

The deflector is essentially an rf cavity operating at 350 MHz, with two parallel plates along the symmetry axis. Any misalignment of the deflector cavity would mean misalignment of the parallel plates leading not only to distortion of beam bunches but modulation of the output beam as well.

Angular misalignment in the x-z (horizontal) plane (yaw angle) affects both x and z components of the field. The two components are responsible for the transverse horizontal deflecting kick and the energy gain (loss) respectively. A pitch angle i.e. angular misalignment in the y-z (vertical) plane of ± 5 mil in 26.2 cm (length of the buncher) has no effect on the x-component, the deflecting component of the field. Its effect on the z-component is negligibly small and does not contribute to the y-component (ideally zero). Any translational misalignment errors in the x-z or y-z plane do not affect the beam in so far as merger along the symmetry axis is concerned.

We applied errors of ± 5 % in amplitude of the rf field, ± 5° in phase angle along with a yaw angle of ± 5 mil in 26.2 cm simultaneously. Combined error of such magnitudes does not result in any additional growth of the emittance nor does it show any significant variation of the output Twiss parameters.

Summary

An error study on the conceptual design for the APDF funnel section was performed. Sensitivity of the design to various errors such as input beam errors, quadrupole errors, buncher errors, and deflector errors have been examined. In all cases, the tolerances on the component alignments and operations are well within the attainable limits of the present day capabilities.

References

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