Microwave and Beam Optics Design Features of a Preinjector Linac for a Synchrotron Radiation Source

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Abstract

This paper discusses the microwave and beam optics parameters of a chopper-prebuncher injection system and a 55MeV 2998MHz, 2.8m long accelerator waveguide assembly designed to produce inherently sharp beam energy spectra (½%) over a range of booster injection pulse periods from approximately 200 to 1½ns. The dc-biased 2998MHz chopper and prebuncher system is designed to inject into the accelerator waveguide sharply defined bunches with essentially all of the charge contained in less than 15 degrees of longitudinal phase space and with a narrow spread of electron velocities. Also, the single section, nonuniform impedance waveguide structure is designed to prevent energy spectrum broadening (typically from asymptotic off-crest bunch location during acceleration) by combining correlated energy-phase orbits with a nodal "detuned" circuit arranged to give two opposing over-the-crest phase drifts when the linac is operated at precisely six times the booster frequency. Manufacturing details are discussed, and photographs of the final fabricated equipment are shown.

INTRODUCTION

The preinjector linac was designed to operate in either (a) a stored energy short pulse mode to inject 8×10^8 accelerated electrons into the booster ring in a time interval of approximately one third of an RF cycle of the 499.65 MHz booster frequency, and with a beam energy spread of less than ±0.3 percent, or (b) a steady state linac long pulse mode in which short terminating portions of the beam pulse, over a range of 300ns, can be selected for injection into the booster ring with an energy spread of less than ±0.4 percent and at a rate of 3×10^8 electrons per booster RF cycle.

The electron gun to linac beam line comprises a low aberration, three lens optics configuration incorporating a 3GHz chopper-prebuncher system and beam collimators designed to accommodate a 140kV SLAC-type gridded electron gun that is operated over a 10:1 range of pulse currents with a maximum value, in the short pulse mode, of 1.5 A.

The traveling wave, $2\pi/3$ mode bunching and accelerating structure has an RF filling time of 780ns and is designed to operate at a loaded beam energy slightly in excess of 50MeV with a peak RF input power of 28MW. 3GHz power is transmitted from the klystron to the linac via an evacuated (10^{-8}Torr), thickwall OFHC copper rectangular waveguide network that includes three high directivity directional couplers for protection and monitoring of the klystron and for drive power to the RF chopper and prebuncher cavities.

A single RF source, short coaxial cable drive lines, and short beam drift distances consistent with the gun HV stability, ensure maintenance of a stable phase relationship between the low Q chopper and prebuncher cavity fields and the high field accelerating structure. For a given phase relationship, interaction of the velocity modulated, sharply defined (RF chopped) short bunches with the retarding standing wave electric field pattern at entry[1] to the accelerator waveguide establishes an energy-phase correlated charge distribution that is maintained during the subsequent bunching and acceleration process. Combining this correlated bunch charge with a distribution of decreasing phase velocities, arranged to give two opposing over-the-crest compensating phase drifts, results in γ convergent phase orbits and allows this single section accelerator configuration to exhibit inherent narrow energy spectrum characteristics.

General specifications of the preinjector linac are listed in Table I.

TABLE I

GENERAL SPECIFICATIONS

Linac Operating Frequency	2997.9 MHz
Klystron Peak RF Output Power.	30 MW
Nominal Pulse Repetition Frequency . . .	10 Hz
Loaded Beam Energy	50 MeV
Accelerator Waveguide RF Filling Time .	780 ns
Accelerator Waveguide Stored Energy . .	13 joules
Normalized Geometric Beam Emittance .	$<100\pi$ mm-mrad
Steady State Mode	
Pulse Length of Steady State Beam Selected for Booster Injection, adjustable up to .	300 ns
Number of Electrons Injected in any Three Contiguous 3GHz RF Bunches. .	1.5×10^8
Steady State Beam Energy Spread.	$<\pm0.4$ percent
Short Pulse Mode	
Linac Beam Pulse.	1.8 ns
Number of Electrons Accelerated in a Time Interval $<$700ps per Pulse.	8×10^8
Beam Energy Spread.	$<\pm0.3$ percent
Peak Pulse Current at Entry to 3 GHz Chopper	1.1 A

CENTERLINE BEAM OPTICS

The linac injection optics elements comprise three thin lens assemblies, a relatively large diameter initial collimator to intercept the electron gun beam halo, a dc-biased chopper-prebuncher system including a water cooled chopping colli-

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mator located between the second and third lenses, and an injection collimator and magnetic pole piece at entry to the accelerator waveguide and associated solenoid assembly.

The three lens configuration was designed to ensure that the wide variation of electron gun beam geometry (beam divergence, waist diameter and position) associated with the 10:1 operational range of pulse currents would be matched to the requirements of the chopper-prebuncher system, especially that of maintaining a constant beam diameter at the entry plane of the chopping collimator regardless of the pulse current setting. This concept is illustrated in Figure 1 showing the beam envelope from the gun cathode through the three lens assemblies to the entry plane of the accelerator waveguide, for pulse current values of 0.15 and 1.5A. The chopper-prebuncher assembly and the chopping collimator are located between lenses 2 and 3. It can be noted that despite the wide variation of beam divergence at entry to lens 1, a constant beam diameter can be maintained at the chopper collimator with a relatively small adjustment of the lens 1 and 2 focal lengths.

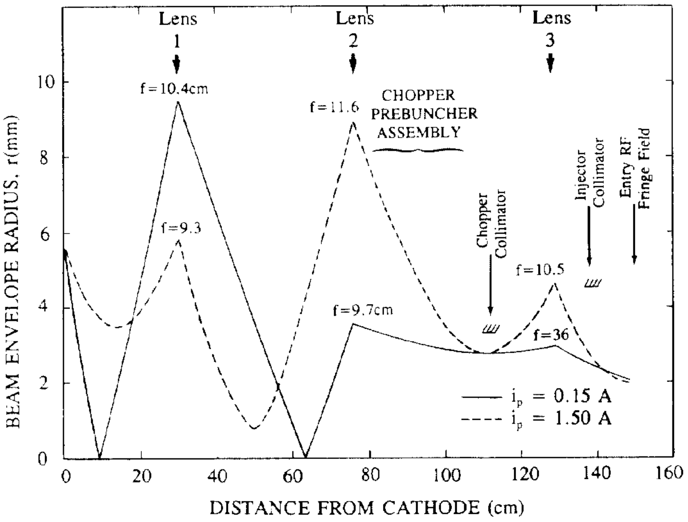

Figure 1. Beam Envelope Radius as a Function of Distance from Cathode for Pulse Current Values of 0.15 and 1.5A.

Chopper-Prebuncher System.

After passing through lens 2, the convergent beam is RF scanned in a vertical plane using a TM_{110} transverse magnetic field chopper cavity[2] and then velocity modulated using a TM_{010} prebuncher cavity. A dc magnetic dipole assembly (integrated into the chopper cavity) is used to bias the scanned beam vertically downward below the centerline so that only a fraction of the incident beam during a given (adjustable) period of each RF cycle is transmitted through the chopping collimator located on centerline downstream. With this biasing technique, the scanned beam is returned to the centerline once per RF cycle, and electrons are injected into the accelerator during a period when the RF deflection is at a maximum and passing through a reversal, i.e., when $\partial V_{RF}/\partial \omega t$, $p_\perp$ and $\partial p_\perp/\partial \omega t \rightarrow$ zero. A photograph of the linac injection system illustrating the lens and chopper-prebuncher assemblies is shown in Figure 2.

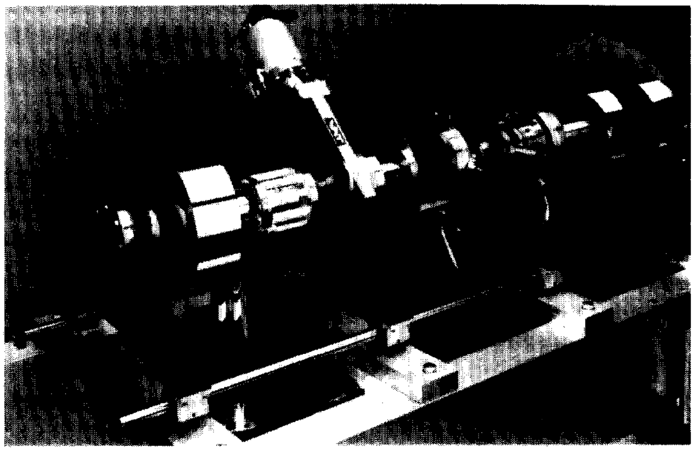

Figure 2. Linac Injection System showing the Three Lens Assemblies and the 3 GHz Chopper-Prebuncher

For the chosen design ratios of chopper collimator to beam diameter of 1.2 and RF deflection amplitude to beam diameter of 2.0, an RF chopped bunch length of 100 to 120° is transmitted through the chopper collimator when the dc bias deflection is made equal, and opposite, to the maximum RF deflection.[3]

Use of the prebuncher cavity results in an order of magnitude phase compression of the RF chopped bunch prior to injection into the linac. This is achieved by adjusting the phase relationship between the chopper and prebuncher cavities so that particles traversing the midplane of the chopper cavity at a period of maximum deflection subsequently traverse the midplane of the prebuncher cavity at a time when the velocity modulating electric field is passing through zero from a retarding to an accelerating field.[4]

Figure 3 shows a simulation of the space charge influenced kinetic energy and charge distributions within the bunch as it drifts from the chopper collimator, through the focusing lens 3, to the RF fringe field at entry to the accelerator waveguide. These chopped beam bunching computations, based on an initial prolate spheroidal nonuniform charge distribution[5] (assuming circular symmetry), indicate

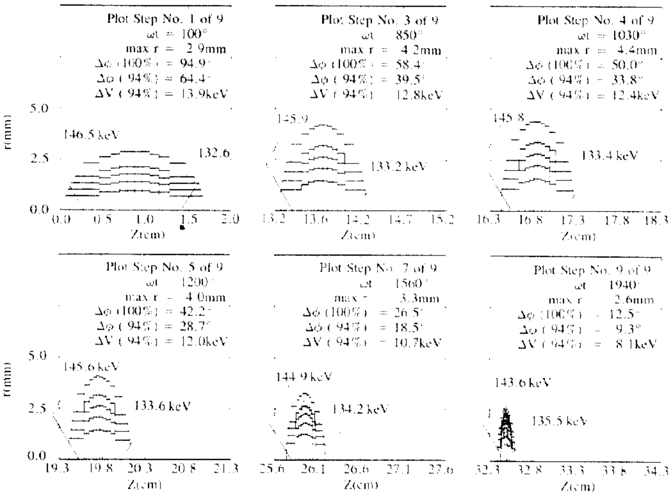

Figure 3. HRC-PRELOR Plots Showing Progressive Bunch Compression Prior to Injection into the Accelerator Waveguide (for 10^8 electrons/3GHz bunch and V_o = 140 kV).

that with 10^8 electrons per 3 GHz bunch, greater than 90 percent of the charge is injected into the accelerator with a longitudinal phase space of less than 10 degrees and a total energy spread of 8keV, i.e., less than 50 percent of the energy spread initially introduced by the prebuncher (19kV) is injected into the accelerator. The final plot steps in Figure 3 indicate that a relatively large reduction of energy spread occurs in the terminating region of the drift space where the combined action of the prebuncher and lens 3 results in a substantial radial and longitudinal compression of the bunch and a rapid growth of the space charge fields.

Accelerator Waveguide Phase Orbit Characteristics.

The accelerator waveguide input coupler cavity is designed to have a SW peak E-field of 280kV/cm at an RF input power of 28MW. The optimum injection phase at 140kV occurs for particles entering the fringe field 20 to 30 degrees after the E-field at the center of the cavity has commenced to decay from its peak retarding value. Early particles experience a greater initial reduction in energy than late arriving particles, causing the bunch width to be uniformly reduced (without phase crossovers) to approximately 2 degrees at the midplane of the cavity and producing an exit array of energy-phase correlated orbits, as indicated in Figure 4. (Particle orbit minimum energies range from 96 to 115keV and occur approximately 15mm before reaching the cavity midplane.) This correlation, with the leading phase at the lowest energy, is inverted in the sixth cavity and is then maintained along the structure; and the spectral width increases and then narrows as the bunch drifts first 15 degrees behind and then 13 degrees ahead of the crest, as indicated in Figure 5. These phase drifts are achieved using a waveguide entry to exit phase velocity distribution of 0.9975 to 0.9957c. Earlier injection of the bunch, when the retarding E-field is at its maximum, produces phase crossovers and lower values of orbit minimum energy before the particles reach the input cavity midplane, causing the inherent energy spread of the emergent beam to increase. Figure 6 shows the emergent beam energy dependence on bunch entry phase for the Figure 3 injection conditions and a constant klystron voltage.

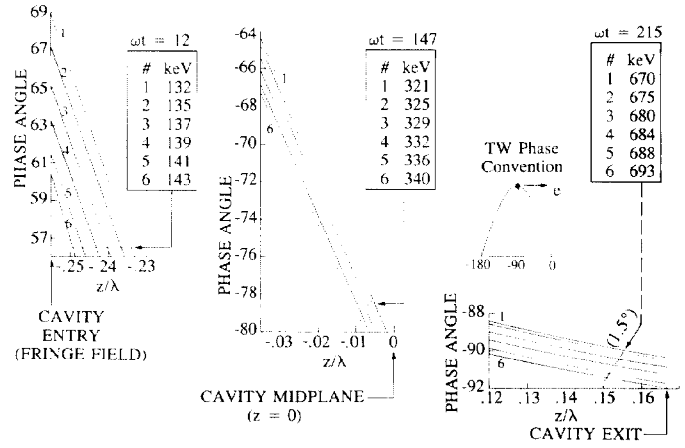

Figure 4. HRC-ELOR Input Coupler Progressive Phase Orbit Plots for the Figure 3 Injection Conditions and P_o = 28 MW.

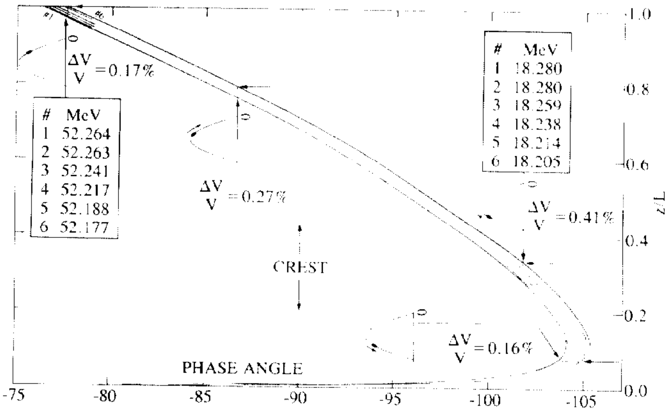

Figure 5. HRC-ELOR Phase Orbit Plots Showing Phase Drift and Reduction of Energy Spread along the Accelerator Waveguide for the Figure 3 Injection Conditions and P_o = 28MW.

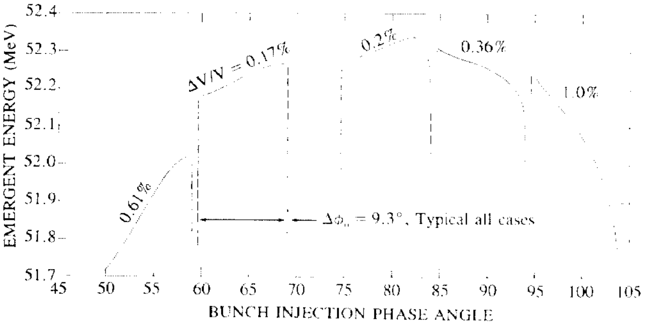

Figure 6. Emergent Energy vs Bunch Injection Phase Angle for the Figure 3 Injection Conditions and P_o = 28 MW (ΔP_o=0).

Figure 7 shows a view of the 50MeV linac centerline including the solenoids, magnetic shielding, water cooling connections and the special shear mounts used for shipping. Compact design, magnetic stainless steel internal yokes and pole pieces and the use of return shielding on all focusing elements resulted in the linac lens and solenoid assemblies having a total dissipation of less than 2 kW.

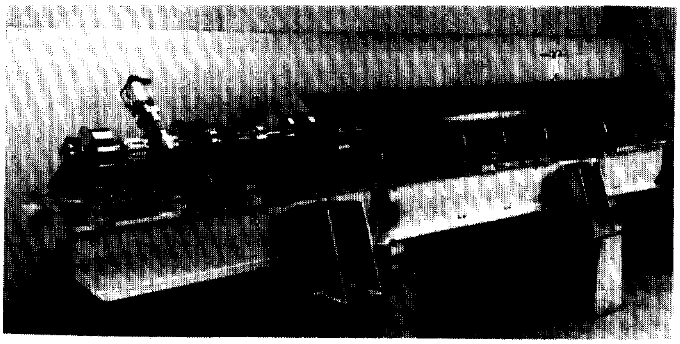

Figure 7. Overall View of the 50 MeV Linac Beam Centerline Assembly.

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