INITIAL PERFORMANCE OF A 500 kV, CHOPPER PREBUNCHER INJECTION SYSTEM FOR A 17 GHz LINAC*

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Abstract

The design features of a 17 GHz chopper prebuncher injection system are described, and initial test results operating with a 500 kV low emittance electron gun and single section 17 GHz linac are presented. The 17 GHz traveling wave relativistic klystron that provides RF power to the linac structure, and the 500 kV electron gun that forms the low emittance ($\beta\gamma\varepsilon = 3\pi$ mm-mradian) source for the injection system, are pulsed simultaneously using the MIT Plasma Science and Fusion Center HV modulator [1]. The HV injection system is designed to produce RF bunches of 15° to 20° for injection into the linac structure, with subsequent compression to approximately 1 degree to provide sub-picosecond bunch operation over an energy range of 10 to 20 MeV with steady-state pulse currents of up to 250 mA. The use of an economical, on-line diagnostic system having the capability of accurately measuring the short RF bunch performance of the 17 GHz linac would be highly advantageous; and a simple technique of accomplishing this, using higher order mode 17 GHz cavities, is discussed.

1 INJECTION SYSTEM DESCRIPTION

The design and beam optics characteristics of the injector and 17 GHz linac have been presented elsewhere [2,3], and the system is briefly summarized as follows.

Three low aberration thin lens assemblies enable the beam to be transported from a 500 kV 1.2A low emittance source through a 17 GHz chopper cavity and a high gradient, velocity modulating prebuncher cavity, a ϕ 2 mm chopping collimator and a small injection aperture at the entry of the linac structure. A dc magnetic dipole, located at the chopper cavity, is used to bias (offset) the RF scanned beam vertically downward below the centerline. With this dc biasing technique, the RF scanned beam is returned to the centerline once during each RF cycle so that a given (adjustable) fraction of the incident beam is transmitted through a small diameter chopping collimator and injected into the linac only during the period when both the energy spread and the rate of change of the transverse momentum introduced by the chopper cavity are tending to zero. The phase width (bunch length) of the transmitted portion of the chopped beam is a function of the ratio of collimator to beam diameter (D/d), the maximum RF deflection of the beam (χ_M) and the dc bias deflection (B). The 17 GHz chopped beam transmission for both the unbiased (symmetrically scanned beam) and biased operating conditions are shown in Figures 1 and 2, respectively. With biased operation ($B=\chi_M$), a χ_M value equal to 3 beam diameters is required to produce chopped bunch lengths of 100° for subsequent compression to 15° by the prebuncher cavity. The chopper cavity was designed to achieve this beam deflection with a drift distance of 35 cm using an RF peak input power of only 1.4 kW to give a peak transverse magnetic field of 6060

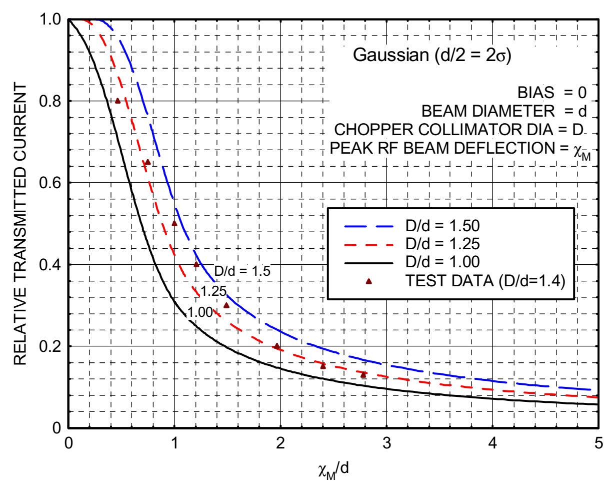

Figure 1: Relative Transmitted Current of Symmetrically Scanned Beam (BIAS=0) for D/d Ratios of 1.0, 1.25 and 1.5 showing Comparison of Theoretical and Experimental Data.

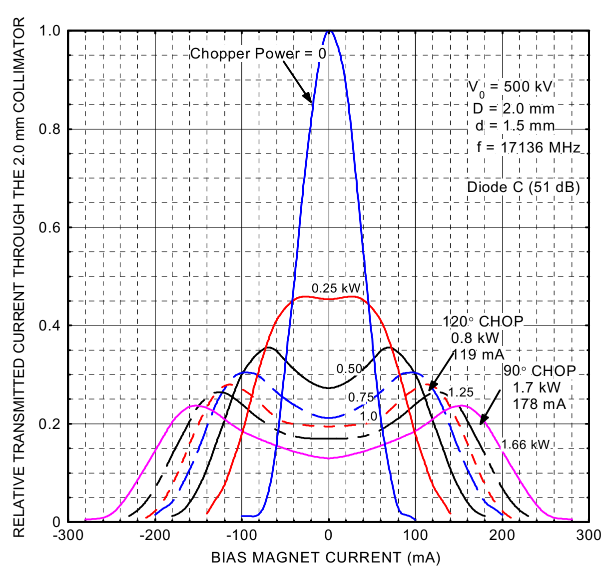

Figure 2: 17 GHz Linac Injection Current versus Chopper Input Power and DC Bias Magnet Current.

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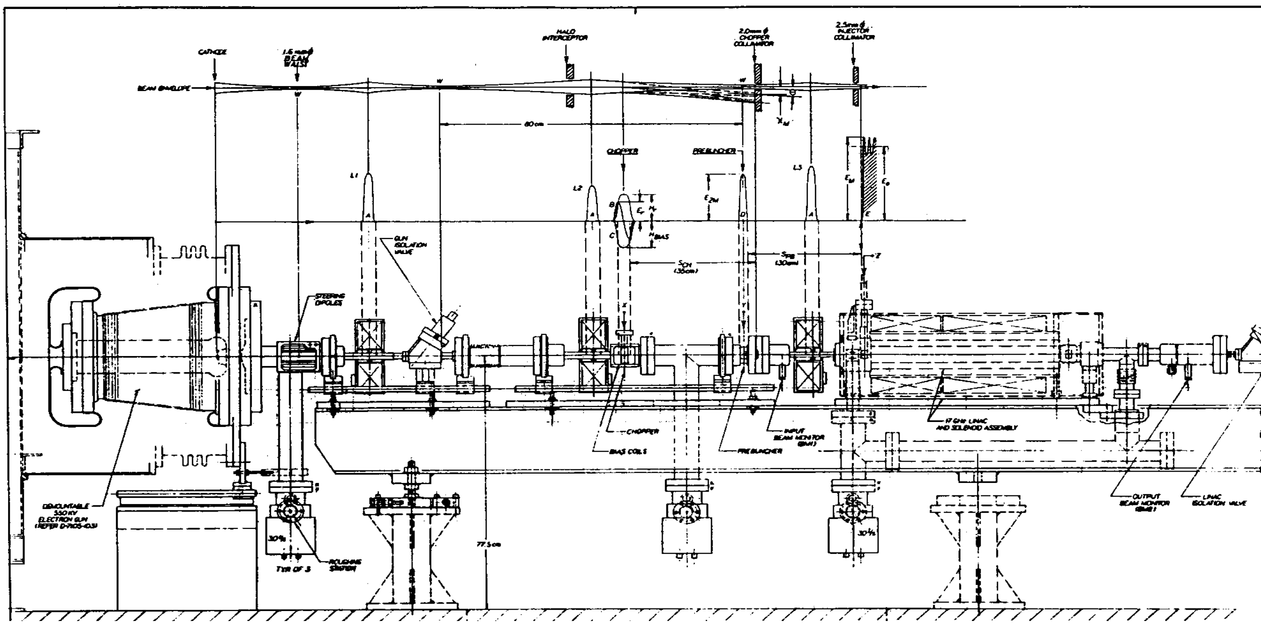

Figure 3: Beam Centerline Layout of HV Injection System and 17 GHz Linac.

A/m at a loaded Q of 780. The prebuncher cavity was designed to operate with a drift distance of 30 cm using an input power of 1.5 kW to give a peak RF field of 90 kV/cm. Independently controlled phase shifters are used to correctly adjust the phase relationship between the injector cavities and the linac. An overall layout of the beam centerline system is shown in Figure 3.

2 INITIAL PERFORMANCE

During high power RF processing of the 2π/3 mode 17 GHz accelerator structure, the onset of RF breakdown was encountered at a surface gradient of approximately 100 MV/m. The maximum surface gradient of this 94 cavity structure occurs in cavity 76 [3] and has a theoretical value of $30.5[P_0(MW)]^{1/2}$ MV/m. The linac input RF power (P_0) was maintained below the arcing threshold to prevent the possibility of iris damage, while still providing accelerating gradients of 40 to 45 MeV/m. Subsequent borescopic examinations identified superficial gray-colored spark marks on the iris contours of cavities 74 to 79 only, and the absence of erosion damage suggested that higher levels of RF processing could be tolerated.

Typical electron beam and RF waveforms obtained with the system operating under heavy beam loading conditions using only the prebuncher cavity (no chopping) and a 1/4 µs wide klystron drive signal, are shown in Figure 4. The load RF signal delay and the small reduction in the width of the linac output beam pulse, compared to the linac input RF pulse, are consistent with the 58 ns filling time of the linac. With a linac pulse current of 500 mA and with the solenoid focusing coils de-energized, a beam diameter of 1.1 mm was measured at the output of the linac. Beam energy spectrometer measurements have confirmed the theoretical beam loading derivative of 13.3 MeV/A [3], and the spectrum dependence on the injector phase settings is presently being investigated using 2% analyzing slits.

The effect of energizing the chopper, without dc biasing the beam, is shown on the linac input (BM1) and the linac output (BM2) beam monitor waveforms in Figure 5. The "bite" removed from the gun pulse in BM1 represents the loss due to the 1/4 µs pulsed chopper symmetrically sweeping the beam across the chopping collimator.

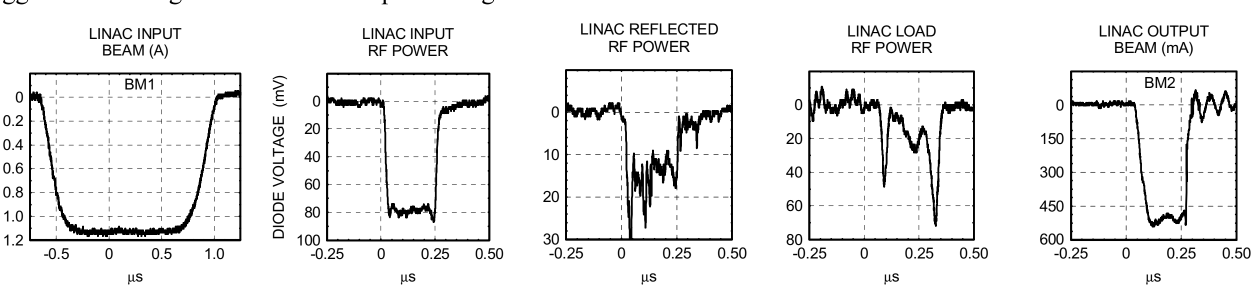

Figure 4: Electron Beam and RF Waveforms under Heavy Beam Loading Conditions using Prebuncher Only.

This 40% loss was produced with 150 W of chopper power giving an χ_M/d of only 1 (refer Figures 1 and 2).

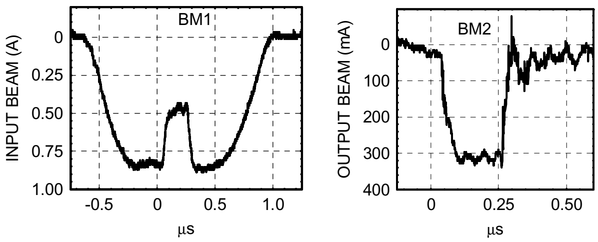

Figure 5: Linac Input and Output Beam Waveforms for Unbiased and Lightly Chopped Injection Conditions.

With biased chopper operation, the BM1 waveform in Figure 6 shows that the gun pulse current on each side of the RF pulse has been intercepted by the chopping collimator, and that a 330 mA 1/4 μs chopped and prebunched beam is injected into the linac. The Figure 6 BM2 output waveform shows that a large fraction of the injected beam is accepted and accelerated through the linac. Under these conditions, with correct phasing, pulse current transmissions of 94% have been achieved. A troublesome feature, yet to be corrected, is the excessive noise level on the diagnostic signals, especially noticeable on the BM2 waveforms.

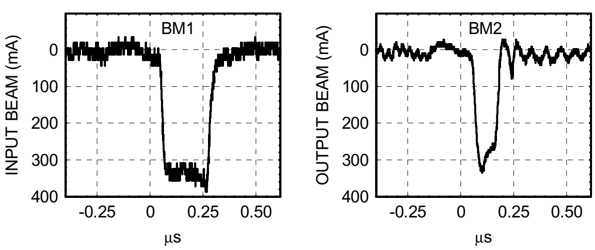

Figure 6: Linac Input and Output Beam Waveforms for Biased Chopper/ Prebuncher Operation.

Typical acceptance and transmission characteristics of the 17 GHz single section linac are summarized in Table 1 for the different injection conditions.

Table 1: Linac Transmission Characteristics

Operating Condition	Linac Injection Current (mA)	Linac Output Current (mA)	Percent Transmission
No prebuncher and no chopper	1180	270	23
Prebuncher only	1180	550	47
Biased chopper and prebuncher	330	310	94

3 FUTURE PLANS FOR SHORT BUNCH DIAGNOSTICS

Several desirable beam experiments remain to be performed to optimize the injected bunches and to investigate the limit of resolution that can be achieved with this 17 GHz linac system. Since the chopper-prebuncher has the capability of adjusting the linac bunch within the range of 100 to 1000 fs, it would be highly advantageous to install an on-line short bunch diagnostic for monitoring and optimizing the linac performance to satisfy the requirements of a given experiment. Future plans include the design of a Smith-Purcell radiation bunch length diagnostic [4]; and the design of a circularly polarized, beam deflecting microwave structure [5] for accurately measuring the geometric and spectral characteristics of the linac beam bunches.

With a phase coherent high power 17 GHz deflection system, it will be possible to transform the longitudinal charge distribution of the linac beam into a highly amplified image displayed in the transverse plane with the electron bunch phase and energy distributions projected in orthogonally differentiated azimuthal and radial directions. Because this time domain technique (a) has the capability of eliminating the uncertainties in phase width measurement caused by energy spread overlay, and (b) has an inherent precision phase calibrating characteristic ($1/f=2\pi\chi_M$), it offers a simple, on-line diagnostic for the definitive measurement of very short RF bunches. Preliminary calculations indicate that using the remnant RF power from the linac structure, a 15 MeV beam can be deflected over a 2 m drift distance to provide a spatiotemporal resolution of greater than 240 fs/mm using a moderately focused, ϕ 1/4 mm beam. Moreover, even the phase uncertainty due to this finite dimension can be normalized-out by phase scanning [6] the linearly polarized deflected beam across analyzing slits located on-axis.

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