A High Charge Injector for the TESLA Test Facility

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Abstract

Several possible models for a high charge injector for the TESLA Test Facility (TTF) have been studied. The injector is required to produce 5×10^{10} e$^-$/bunch with a pulse length of $\sigma_z = 1$ mm during a macropulse length of 800 μs and a duty cycle of 1%. Two possible schemes are discussed, one starting with a 250 kV thermionic gun and a second starting with a 500 kV DC photocathode gun. The thermionic case requires initial bunching using two subharmonic cavities, while the photocathode gun solution does not. It is demonstrated that a short, normal conducting buncher operating a ~5 MV/m can then efficiently preaccelerate the beam. It is finally accelerated through a 9-cell superconducting capture cavity and compressed to the required bunch length using a chicane-type magnetic buncher. Simulations of the entire injector for both cases show that the needed bunch length can be obtained with a final emittance of $\sim 50\ \pi$ mm mrad.

1 INTRODUCTION

The Tesla Test Facility (TTF), presently under construction at DESY, requires an injector able to produce not only very high charge (5×10^{10} e$^-$), but also very short bunches ($\sigma_z = 1$ mm). A number of such injectors are already in existence or in the planning stages [2, 3]. Direct application of one of these injectors for the TTF injector would be difficult, however, as TTF requires a requires a long macropulse (1 ms) and a high duty cycle (1%). For this reason a simpler injector (injector #1) has been built first [1], delivering the same macropulse current (8 mA) but in 216 MHz bunches instead of the 1 MHz bunches for the high charge injector. It will consist of a 250 kV gun and a 216 MHz buncher injecting directly into a 9-cell superconducting (SC) cavity powered by a separate 250 kW klystron. The high charge specification will only be achieved by injector #2.

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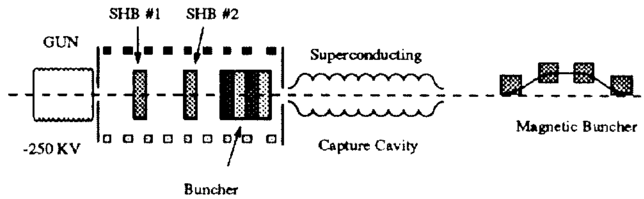

Figure 1: A schematic of the injector model using a thermionic gun.

An RF gun is a possible solution for injector #2, but the required photocathode, laser system and rf cavity would be pushing the limits of the present state of the art due to the high duty cycle and long pulse length. We have proposed to study a conventional scheme, using also a thermoionic gun and 2 subharmonic prebunchers, which is the topic of this paper. A model using a DC photocathode gun has also been studied. Simulations with PARMELA [4] are presented and the use of PARMELA is discussed.

2 INJECTOR MODELS

2.1 *Thermionic Gun Model*

A schematic diagram of the injector is shown in figure 1. A model for using a thermionic gun was inspired by a design for the NLC injector described by R. Miller [5]. The gun is assumed to operate at 250 kV and emit $5\times10^{10}\ e^-$ in a rectangular pulse 350 ps wide. A gun with similar properties, 170 kV and $2\times10^{10}\ e^-$ in 350 ps FWHM (700 ps FW), has been reported [6]. Initial bunching is performed by two 650 MHz subharmonic bunchers (separated by ~50 cm).

For high charge injectors it is necessary to immerse the beam (from the gun on) in a continuous solenoidal field to counteract the huge space charge forces. As this is not possible to do with a SC capture cavity, it is proposed to pre-accelerate and bunch the beam using a 4-cell, $\beta = 1$ normal conducting (NC) buncher. Assuming a shunt impedance of 50 MΩ/m and a total length of ~50 cm, 250 kW of power is required to ob-

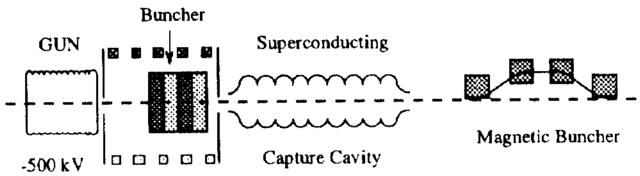

Figure 2: A schematic of the injector model using a photocathode gun.

tain an accelerating field of 5 MV/m. This is the same value as is required to power the SC capture cavity for the low charge injector for TTF, so an identical klystron and modulator could be used. This buncher is located 25 cm after the second subharmonic cavity.

After the NC buncher, it is planned to use the 9-cell SC capture cavity of the low charge injector to boost the beam energy. The distance between the NC and SC cavities should be as short as possible, and the length surrounded by a solenoidal field. To obtain the desired final bunch length, the accelerated beam is further compressed using a chicane-type magnetic buncher (MB).

A basic chicane-type magnetic buncher is a relatively simple achromatic system, requiring only four identical rectangular bending magnets. The path length variation of the MB can be adjusted by changing the bend angle to match the phase-energy corrleation of the beam from the RF bunching system. The MB in these simulations uses dipole magnets 15 cm long with bend angles of $\sim 30°$ for an overall length of $\sim$1.2 m and a resulting $R_{56} = -.17$ cm/%.

2.2 *Photocathode Gun Model*

Figure 2 shows an alternative model using a high-voltage DC photocathode gun as an electron source. This is not exactly an off-the-shelf item, but it has properties which are interesting enough to warrant an investigation. Such a gun is now under construction at CEBAF [7] for use as an injector for their FEL project, and is designed to produce 0.12 nC, 100 ps bunches at 500 keV using a GaAs photocathode. Simulations show [8] that it is capable of producing the 8 nC bunches needed here with an emittance of 30 π (all emittances are normalized, rms values with units of mm–mr) and a beam radius (diverging) of 2.6 cm.

The ability to generate 100 ps bunches obviates the need for subharmonic bunching, and allows direct injection into the NC capture section. This feature makes the injector much more compact and reduces the number of components in the beamline. In addition, since the gun needs only a 500 kV DC power supply (commercially available) for operation, a complicated and space consuming modulator is not required. Some disadvantages are the need for semiconductor photocathode processing techniques, as well as an expensive laser system.

3 BEAM DYNAMICS

3.1 *Introduction*

The space charge forces on the macroparticles in PARMELA are calculated in the usual fashion by superimposing a 2-D cylindrically symmetric mesh over the particle distribution in the rest frame of the bunch and determining the fields due to the particles in the bins. This method has the advantage of running quickly, but there are many free parameters to set so one must carefully check output variations with changes in these parameters.

Since the bunch length changes dramatically during the bunching process, it is important to vary the total mesh length in the longitudinal direction as the bunch compresses. We have introduced a routine in PARMELA to automatically do this. Using this adaptive meshing method gives convergent results for the final emittance using the smallest number of bins (25) compared to requiring over 50 bins for convergence when the initial mesh length is not varied (see [9] for complete details of this and of all the simulations described in this report). This is important to know as one wants to use as few bins as possible in order to speed up execution. The meshing in the radial direction is not as important as the radial beam dimensions do not vary so dramatically.

In these simulations, PARMELA hard edge solenoids are used to model the magnetic field along the beamline and the subharmonic bunchers are represented using a zero-length, ideal buncher with a sinusoidal field. The normal-conducting buncher is described using the internal field values provided in PARMELA for a 1300 MHz Los Alamos side-coupled structure. The accelerating field for the entire 9-cell SC cavity is calculated using URMEL and a Fourier transform of the fields is included in a separate subroutine.

3.2 *Thermionic Model Results*

Figure 3 shows the radial and phase variation and emittance growth of the beam for the thermoionic injector model. The bunch is compressed by a factor of $\sim$ 30 to reach a final bunch length of $\sigma_z = 1.4°$

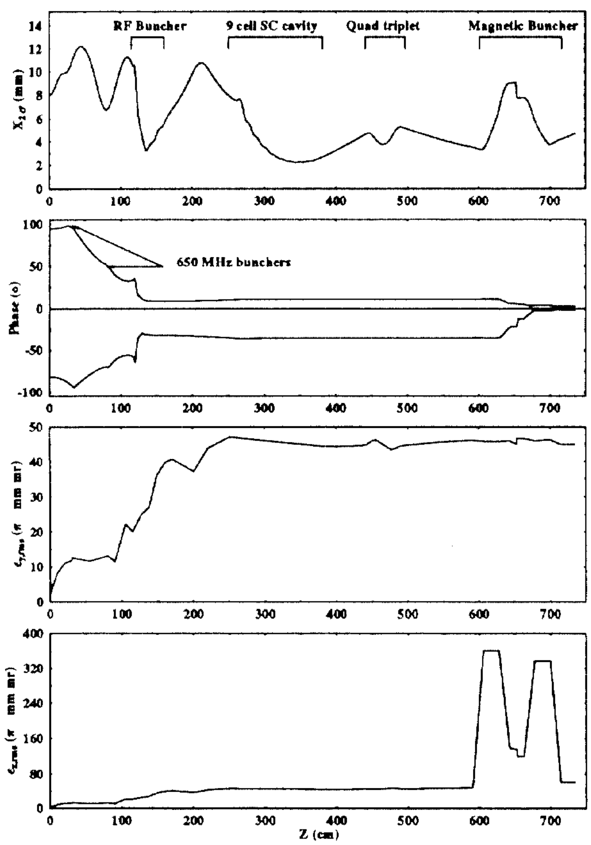

Figure 3: The top figure shows the 2-σ beam envelop for the horizontal plane and the second figure shows the phase compression envelop. The bottom two figures show the emittance growth in the vertical and horizontal planes.

at an energy of 16 MeV. The emittance grows by a factor of 12 to 45 π in the vertical plane, and to 65 π in the horizontal plane after passing through the MB. Without space charge the horizontal emittance explodes in the bending region, but cancels out at the end of the achromatic magnetic buncher system. With space charge the dispersion is no longer suppressed and a net emittance growth results. All of the parameters were optimized to keep the emittance growth as small as possible while obtaining a good phase compression.

3.3 Photocathode Gun Model Results

The plots for the photocathode gun model are similar to those for the thermionic model and are not shown here (see [9]). In this case, it was possible to reach a final bunch length $\sigma_z = 2.2°$ without using a MB by phasing both the NC buncher and the SC cavity off crest. The resulting emittance is high (75 π), though, and the energy is low (13 MeV). By varying the phases, it is possible to obtain a beam with an energy of 16 MeV and an emittance of 60 π, but a MB is required.

4 CONCLUSION

From the simulations performed here, one can conclude that an injector can be built that will fulfill the requirements for a high charge injector for the TESLA Test Facility. Such an injector would consist of an electron gun (either thermionic of photocathode), two subharmonic bunchers (not necessary for the photocathode gun), a 4-cell, normal conducting buncher, a 9-cell superconducting structure, and a magnetic buncher. The exact details of the models depend very strongly on the actual properties of the electron gun to be used. For future simulations, the model should include the measured parameters of an existing gun, as well as more realistic characterizations of the the elements of the injector. Effects such as wakefields, beam loading, and instabilities have not been included.

5 REFERENCES

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