First Tests of the 250 keV Electron Source and Beamline for the TESLA Test Facility Injector.

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Abstract

The TESLA Test Facility (TTF) uses an electron source consisting of a 30 kV thermionic triode gun followed by an electrostatic accelerating column to increase the beam energy to 250 keV. The gun cathode is modulated at 217 MHz to provide sub-nanosecond micropulses within the 800 μs macropulse. The beam is then transported to superconducting 'capture' cavity through a 3 m long beamline equipped with solenoidal focusing lenses, a 217 MHz pre-buncher cavity and several beam monitors. The gun, its associated electronics and the transfer beamline have been assembled and tested. We present the first measurements of the beam emittance under the nominal operating condition of 8 mA average current in the macropulse. These measurements are found to be consistent with measurements made on the 30 kV gun alone and with simulations of the transport through the electrostatic column.

1 INTRODUCTION

The design of the TESLA Test Facility Linac Injector has been described previously[1]. Here we report on the first operation of the "pre-injector". This consists of a 250 keV electron source followed by a 3 m transport line. The transport line contains solenoidal magnets to provide transverse focusing and a 217 MHz pre-bunching cavity to longitudinally compress the microbunches leaving the source. The injector should provide an average current of 8 mA during an 800 μs macropulse. The macropulse consists of a train of micropulses seperated by 4.6 ns (corresponding to the frequency of the pre-buncher). To meet the average current requirement each microbunch must contain 37 pC. As the micropulses are quasi-'triangular' in form, the peak current is of the order of 115 mA.

2 DESCRIPTION OF THE PRE-INJECTOR

2.1 *The Electron Gun*

The injector employs an electron source in which the beam is first accelerated through 30 kV in a conventional thermionic triode gun and is then further accelerated to 250 keV in a commercially available electrostatic column of 90 cm length. The gun and column are fed by individual power supplies of 40 kV and 300 kV respectively. To obtain a stable voltage (better than $1\text{x}10^{-4}$) during the 800 μs macropulse the column is powered through a 33 nF capacitor. The large stored energy of the assembly, operated in air, calls for careful measures to prevent electrical breakdown and any associated damage. A discussion on the choice of the unusually high source voltage can be found in reference 2. The gun and column are pumped using a 200 l/s pump downstream of the column, although the effective speed at the gun is limited to 35 l/s by the column conductance. Following baking of the gun (80°C) and the column (60°C) the base pressure in the column is typically $4\text{x}10^{-9}$ mbar.

Beside the anode-cathode voltage, three additional voltages determine the gun current. The gun is normally held in "cut-off" by a negative d.c. bias applied to the grid. A combination of two pulses are used to drive the gun into conduction. The first is a positive square wave pulse of variable width (10 μs - 800 μs) applied to the grid at a repetition of 10 Hz or less. The second is a train of negative pulses at 216.7 MHz applied to the cathode. The negative pulses are furnished from a commercial broad band RF amplifier capable of providing outputs of up to -100 V and of duration <1.5 ns. The "portion" of this pulse which switches on the gun can be varied by altering the amplitudes of the grid bias and square wave pulse. Thus the width and amplitude of the micropulse can be independently controlled. The settings of these values were determined following a measurement of the gun characteristic[3].

2.2 *Transverse Focusing*

Transverse focusing is provided by 4 shielded solenoid lenses, denoted L0 through L3. Lenses L0, L1 and L3 provide an integrated strength of 8 x 10^5 G^2cm over an active length of 9.4 cm. The peak field, for a lens current of 2A, is approximately 360 Gauss. Although the beam should be cylindrical in form one of the lenses, L2, is constructed as a double lens, i.e. two lenses with magnetic fields in opposing directions. This lens is used along with a profile monitor (see below) for emittance measurement and its construction ensures that it induces no net rotation of the beam. Each lense incorporates a pair of horizontal and vertical steering elements in which the conductors are drawn onto printed circuit boards. As the beam energy is low there is a strong deflection due to the terrestrial field along the length of the beamline (the vertical terrestrial field component is measured to be 300 mG). A field correcting coil has been installed along the length of the beamline in order to compensate this deflection.

2.3 *Diagnostics*

The beam pulse exiting the column is monitored using a capacitive pick-up electrode. This consists of a ceramic ring with a metallic coating on its inner and outer surfaces. The capacitive signal induced on the electrode can be observed on a fast (1 GHz) oscilloscope and yields the temporal structure of the bunch as well as having an amplitude proportional to the peak current. Measurement of the capacitance in-situ allows the sensitivity of the monitor to be calculated. However, the main function of this monitor is to measure the width of the micropulse. The first profile information is obtained using a 25 mm sq. alumina view screen (VS1) placed 73 cm downstream of the column exit (hereafter referred to as 'point zero'). The screen provides only qualitatative information of the beam size as the observed light intensity is not proportional to the incident beam charge. The average (macropulse) current in the linac is measured using a toroidal current monitor. Details of this monitor, and its use as a differential security device for the linac, can be found elsewhere in these proceedings[4]. A button electrode monitor, based on the design employed at the ESRF[5], is used to provide horizontal and vertical position information.

Quantitative information on the beam profile is measured using a secondary electron emission monitor (SEM-grid). Again, this device is described elsewhere in these proceedings[6]. Essentially it consists of 32 bands of titanium, 12 µm thick and 300 µm wide with a centre to centre spacing of 700 µm. When the beam strikes the bands they emit secondary electrons and the signals obtained from each band give information on the vertical beam profile. Reduction of the data yields numerical values for the rms width, σ_y, of the beam, the full width at half height (FWHH), beam centroid position etc. Although our beamline is composed of cylindrically symmetric elements we have taken the precaution of mounting a second view screen (VS2) in the same diagnostic port as the SEM-grid. This allows us to ensure that our optic gives a round beam at the position of the grid. These monitors, which can be used in turn, are located 260 cm downstream of point zero. Finally, an electrically insulated Faraday cup provides an independent measurement of the average macropulse beam intensity.

3 THEORY

Despite the small charge per microbunch, the low energy of the beam implies that the effects of space-charge during transport are not negligible. Therefore, traditional emittance measurement techniques such as the method of 3-Gradients would not be valid for our beam. Consequently, we employ a technique based on the integration of the Kapchinsky-Vladimirsky (K-V) envelope equation[7]. The K-V envelope equation for cylindrically symetric, constant energy beams can be written as,

$$\frac{d^2a}{dz^2} + K(z)a - \frac{2I}{I_A(\beta\gamma)^3 a} - \frac{\varepsilon^2}{a^3} = 0$$

where I is the total beam current, I_A is the Alfven-Lawson current, K(z) is due to the externally applied fields and β and γ are the usual relativistic parameters. If we take a to be twice the rms radius of the beam then ε is given by four times the un-normalised rms emittance[8]. The emittance of the beam is obtained in the following manner; the rms spot size is measured using the SEM-grid for various settings of the lens L2. For each of these settings we integrate the K-V equation, starting from an arbitrary point upstream of L2 and terminating at the grid location. This is done iteratively using different initial beam parameters (radius, divergence, emittance). The iteration continues until a least-squares-error fit finds the initial beam parameters which lead to the best agreement with the data obtained from the grid. Once these values are determined one can continue the integration of the envelope equation all the way back to point zero.

4 MEASUREMENTS

The first beam transported through the column was obtained in April 1995. With L0 un-powered, and the beam current at the nominal value, the image obtained on VS1 is faint and appears to fill the 25 mm sq. screen. As predicted therefore (see below), the beam is large however it can be easily focussed to a small spot on VS1 using L0. We find that the beam can be transported, apparently without loss, to VS2 using only L0. These measurements were performed without the pre-buncher cavity mounted on the beamline thus avoiding complications due to beam loading.

Repeated measurements of the beam size as a function of the strength of L2 gave highly reproducible results. A typical scan is shown in figure 1. The presence of a collimator restricted the range of spot sizes we could have at VS2 without beam losses. For the smallest values obtained (1.2 mm) it is clear that we are approaching the limit of the resolution of the SEM-grid. We initially worked with measurements of the FWHH and presumed that this would be $2.35\sigma_y$ (as would be the case for a perfect Gaussian distribution). Analysis of this data repeatedely gave normalised emittance ($\varepsilon_n=\gamma\beta\varepsilon$) values of 15 to 16 mm-mrad. However, when one takes the real measured values of σ_y we find that they are always slightly smaller than the FWHH/2.35. The calculated emittance using the measured values of σ_y give ε_n = 12 mm-mrad. When the envelope equation is integrated back towards point zero we find that the beam exits the column with $2\sigma_y$ = 12 mm and with a divergence of 7 mrad. These values are found to be insensitive to emittances in the range of 12 to 16 mm-mrad.

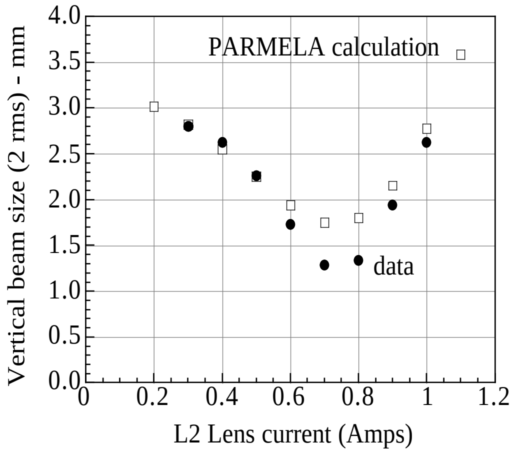

Figure 1. Comparsion of measured beam sizes with calculations using PARMELA.

5 DISCUSSION

Emittance measurements of the beam from the 30 kV gun have already been reported[3]. The measurements were made for a continuous beam, i.e. without RF modulation of the grid. The value obtained for 100 mA varied between 12 mm-mrad and 16 mm-mrad depending on the value of the gun voltage. We have written a computer code which allows us to calculate the transport of the beam through the electrostatic column using the measured beam parameters at the anode exit as input data. The beam size at the column exit is found to be approximately 12 mm, in excellent agreement with the value stated above. In addition the beam divergence at the column exit is 6 mrad, again in good agreement with the above value. We have performed PARMELA simulations through the transport line using the output data from the column calculation as input to PARMELA. The calculated beam sizes at the location of the SEM-grid are shown in figure 1. The calculated values agree well with the measured data. The largest discrepancies are for the smallest beam sizes which approach the limit of the grid resolution.

After the measurements described above were completed the pre-injector was dismantled and shipped to DESY for installation in the TTF linac tunnel. At the time of writing the beam has been transported to the end of the re-assembled beamline with RF power in the pre-buncher cavity. A signal obtained on a coupling loop in the cavity clearly shows the effects of beam loading The optimum phase and amplitude adjustments of the cavity remain to be done.

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