The TESLA Test Facility Linac Injector

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Abstract

The TESLA Test Facility (TTF) Linac is a 500 MeV, 1.3 GHz superconducting accelerator under construction at DESY (Hamburg) by an international collaboration. The linac is being built to demonstrate the viability of the superconducting RF approach to a future e^+e^- linear collider. Within the collaboration three participating French laboratories (LAL, IPN and DAPNIA) have undertaken the task of designing and constructing a phase 1 injector for TTF. We describe the studies towards the realisation of this 7 - 14 MeV, 8 mA high duty cycle (800 µs pulse, 10 Hz repetition rate) injector. The front end of the injector will consist of a 250 keV electron gun, a 216.7 MHz sub-harmonic bunching cavity and a superconducting capture cavity at the main linac frequency. This is followed by a beam analysis line and a transport section to match the beam from the capture cavity to the first cryomodule of the main linac.

1. INTRODUCTION

The TTF linac will essentially consist of an injector, four 12 m long cryomodules each containing eight 9 cell superconducting (SC) 1.3 GHz cavities of length 1.04 m, and a beam analysis line to measure the properties of the accelerated beam. To properly test such issues as HOM dissipation and wakefield excitation requires an injector capable of delivering a train of bunches with the characteristics of the TESLA proposal itself, i.e. 5×10^{10} electrons per pulse at 1 MHz intervals during an 800 µs macro-pulse[1]. In contrast, the problems of operating high gradient (15 to 25 MV/m) SC cavities under high beam loading can be investigated using an injector capable of delivering the same average current albeit at reduced bunch charge and increased repetition rate. With this goal in mind we are constructing a 'phase 1' injector for TTF for which the specification is given in table 1.

Table 1
Specification of TTF phase 1 injector

beam energy	> 5 MeV
average current	8 mA
pulse length	800 µs
bunch length	1 mm (rms)
energy spread	< 1% (rms)
RMS emittance	5 - 10 mm-mrad (normalised)
repetition rate	10 Hz

2. DESCRIPTION OF THE INJECTOR

The principal components of the injector consist of, (i) a triode electron gun capable of delivering micro-bunches with a variable frequency, (ii) a sub-harmonic bunching (SHB) cavity to provide longitudinal pre-bunching of the electron pulses, (iii) a superconducting 'capture cavity' to further bunch the electrons and to provide some pre-acceleration before injection into the linac, (iv) an analysis line to verify the correct adjustment of the beam parameters and (v) a transport section, consisting of two triplet magnets, to match the correctly adjusted beam to the main linac.

The bunch repetition frequency will be controlled by the application of fast (<1 ns) pulses to the gun cathode at the desired rate. The maximum rate of repetition is equal to the frequency of the SHB (216.7 MHz). At this frequency the 8 mA average current corresponds to bunch charges of 37 pC (2.31×10^8 e's per pulse). For good pre-bunching the initial pulse-width should be sufficiently short in comparison with the period of the SHB and we set this to be 640 ps (± 25° of RF phase at 216.7 MHz) which corresponds to gun currents of 115 mA for 'triangular' pulses.

The choice of a superconducting structure (identical to those used in the cryomodules) for the capture cavity is influenced by the long macro-pulse width and consequent high average power that would be required of a copper structure to provide significant pre-acceleration of the beam coming from the gun. On the other hand, the leakage field of the SC cavity and the fact that it is not β-graded, necessitates the use of a gun producing electrons of energy superior to 200 keV.

2.1 *The Electron Gun*

The electron gun will be a modified triode gun, built by Hermosa Electronics (California), and originally employed on the ALS linac at Saclay[2]. After reduction of the anode-cathode spacing we have measured currents in excess of 500 mA at 30 kV. This is largely sufficient to provide the possibility of operating the injector at frequencies lower than 216.7 MHz. The additional energy of the beam will be provided by an electrostatic accelerating column capable of sustaining 300 kV in air, as is employed on the S-DALINAC at the TH Darmstadt[3]. Simulations of the injector using the PARMELA code indicate that we need to maintain the gun voltage to better than 0.1% during the 800 µs pulse if we wish to keep the final beam parameters within the required specification. In order to do this we power the column via a 33 nF capacitor fed by a 300 kV - 1 mA power supply. The risk of electrical breakdown and the consequent release of stored energy in the system presents a major concern for the succesful operation of the injector. Simulations using the EGUN[4] code indicate that not all of the current available from the gun can be reasonably transported through the electrostatic column and so initial operation of the injector will be restricted to 216.7 MHz. However the installation of an 'Einzel' focusing lens at the input to the column holds the promise of increased bunch charge operation at a later date[5].

2.2 *The Sub-harmonic Buncher*

The frequency of the SHB cavity is chosen to be 1/6 of the frequency of the main accelerating cavities in order that its period is sufficiently larger than the gun pulse widths. This is required to ensure good pre-bunching of the beam and to avoid as much as possible the loss of electrons on the SC walls of the capture cavity. The SHB cavity consists of a single re-entrant cell and is fabricated from stainless steel. To provide the cavity with a high quality factor ($Q = 24300$) the inner walls of the cell will be coated with a thin (20 μm) deposition of copper. SUPERFISH calculations indicate that the cavity will have a transit-time corrected shunt impedance ($R_s = V^2/2P$) of 3.11 MΩ. The peak cavity Volts required to provide the necessary pre-bunching is calculated to be 50 keV leading to a modest peak power dissipation of 400 W. In order to provide some margin for safety the cavity will be powered using an RFTS (Bordeaux) amplifier, capable of delivering 2 kW pulses for up to 5 ms at 10 Hz. The amplifier is rated to have a phase stability of ± 0.5° and amplitude stability of ± 0.5% during a 1 ms pulse.

2.3 *The Capture Cavity*

The role of this cavity is twofold; (i) to terminate the bunching initiated upstream. The bunches will have a duration of < 100 ps at the entrance to the cavity and will be compressed by a further factor of 10, (ii) in addition this cavity will provide the necessary energy (7 - 14 MeV) for injection into the first cryomodule, the energy depending on the field at which the strucure is operated. The capture cavity is a standard TESLA cavity (9 cell, 1.3 GHz) identical to the 32 cavities of which the TTF linac is composed. It incorporates all of the new concepts developed for the TESLA project, i.e. the helium vessel integrated to the body of the cavity with a reduced LHe volume (25 liters), and with both the main and HOM couplers located in the cryostat vacuum. This cavity is installed in a special cryostat connected to the cryogenic distribution lines of the linac and is operated at 1.8 K. Although there is sufficient reserve power in the 4.5 MW klystrons which power the main linac cavities (1 klystron per 16 cavities) the capture cavity will be powered with its own individual 300 kW klystron. This will permit improved control of the klystron phase and amplitude thus simplifying the operation of the injector. It should be noted that, as for the main linac cavities, this structure will be operated in pulsed mode in contrast to other SC RF systems which accelerate continuous beams and are constantly powered with RF.

2.4 *Beam Diagnostics*

To verify that the beam has the required characteristics it is necessary to install appropriate instrumentation along the linac. A capacitive pick-up monitor will be used at the exit of the column to monitor the beam pulse from the gun. Current measurements elsewhere will be made with toroidal monitors, in particular, differential measurements of the current before and after the capture cavity will detect the presence of any beam losses and provide a signal to "trip-off" the gun. Beam position monitors (BPM) will be "button electrode" devices as employed at the ESRF[6]. An additional electrode on one BPM will allow a measurement of the RF phase of the beam with respect to the master-oscillator phase.

The transverse profile of the beam will be measured using retractable aluminium-oxide screens. Quantitative information on the horizontal beam profile will be obtained for the 250 keV beam using a secondary electron-emission monitor (SEM-grid). The low range of 250 keV electrons in suitable grid materials make the design of this monitor particularly delicate. A non-rotating magnetic lens upstream of the SEM-grid will enable the calculation of the beam emittance from measured profiles using the '3-gradient' technique.

The transverse profile of the beam after acceleration in the capture cavity will be measured using optical transition radiation (OTR) from a thin metallic foil placed in the beam path. As above, profile measurements for different settings of the first of the triplets will allow calculation of the emittance of the accelerated beam. In particular, the use of an image intensifier coupled to a CCD camera may permit time resolved emittance measurements of a small window (>100 ns) within the macro-pulse. Streak camera measurements of the OTR signal will permit measurement of the bunch length with 2 ps resolution. A second SEM-grid, placed at the focal plane of the bending magnet of the beam analysis line will measure the horizontal profile of the deviated beam thus allowing measurement of the energy dispersion. The SEM-grid will have forty tungsten wires of 0.1 mm diameter placed 2 mm apart and will provide an energy resolution of 0.1%. The vertical profile of the deviated beam will be measured using OTR.

Faraday cups, placed before the capture cavity and the first cryomodule, will be used during commisioning of the linac which will start cautiously with reduced pulse-widths of 10 μs, gradually building up to the full 800 μs pulse-width. X-ray monitors placed in the neighbourhood of beam collimators will provide an alarm in the event of beam scraping.

3. INJECTOR SIMULATIONS

We have performed extensive modelling of the injector beam dynamics from the exit of the electrostatic column to the entrance of the first cryomodule using the simulation code PARMELA[7]. Initial runs were used to optimise the distance from the SHB to the capture cavity for reasonable SHB field amplitudes. The distance between the gun and the SHB is set to a minimum while still allowing space for appropriate elements (pumping, focusing, steering, diagnostics...). The simulation uses the electromagnetic fields of the capture cavity and SHB as calculated from their geometries using SUPERFISH. In the case of the capture cavity the important contribution of the leakage field is taken into account. The final layout of the injector is shown in figure 1. To maintain reasonable transverse beam sizes four magnetic lenses are employed between the gun exit and the entrance to the capture cavity cryostat, their positions and field strengths being optimised in the simulation.

At the time of writing the largest uncertainty among the beam parameters is the size and divergence of the beam which will emerge from the electrostatic column. We assume for the moment therefore, as reference input parameters to the code, a maximum beam radius of 2.5 mm, a maximum divergence of 6 mrad (edge emittance = 15 mm-mrad), an energy of 250 keV, a pulse-width of ± 150° at 1.3 GHz and a bunch population of 2.31×10^8. Initially we have used a capture cavity field corresponding to a maximum energy gain of 15 MV/m but our simulations show that equally good beam characteristics can be found for energy gains as low as 7MV/m. A lower RF field offers the advantage that the RF focusing effect of the cavity is reduced leading to a less divergent beam exiting the structure. This in turn makes the matching of the beam to the linac less sensitive to the setting of the triplets[8]. In addition the required performance of the capture cavity is easier to achieve. The simulations show that de-bunching of the beam in the long (6.36 m) transport section between the capture cavity and the linac is negligible for energy gains of 10 MV/m and we now take this value as our 'reference case'. The final beam characteristics at the exit of the capture cavity are shown in table 2 and can be seen to be compatible with the injector specification.

Table 2
Injector beam characteristics as calculated by PARMELA
(for capture cavity energy gain of 10 MV/m)

Energy	9.9 MeV
RMS phase width	0.77°
Total phase width	3.2°
RMS bunch length	0.49 mm
RMS energy spread	78 keV
Total energy spread	300 keV
Relative energy spread (rms)	0.8%
Norm. rms emittance (both planes)	4.2 mm-mrad

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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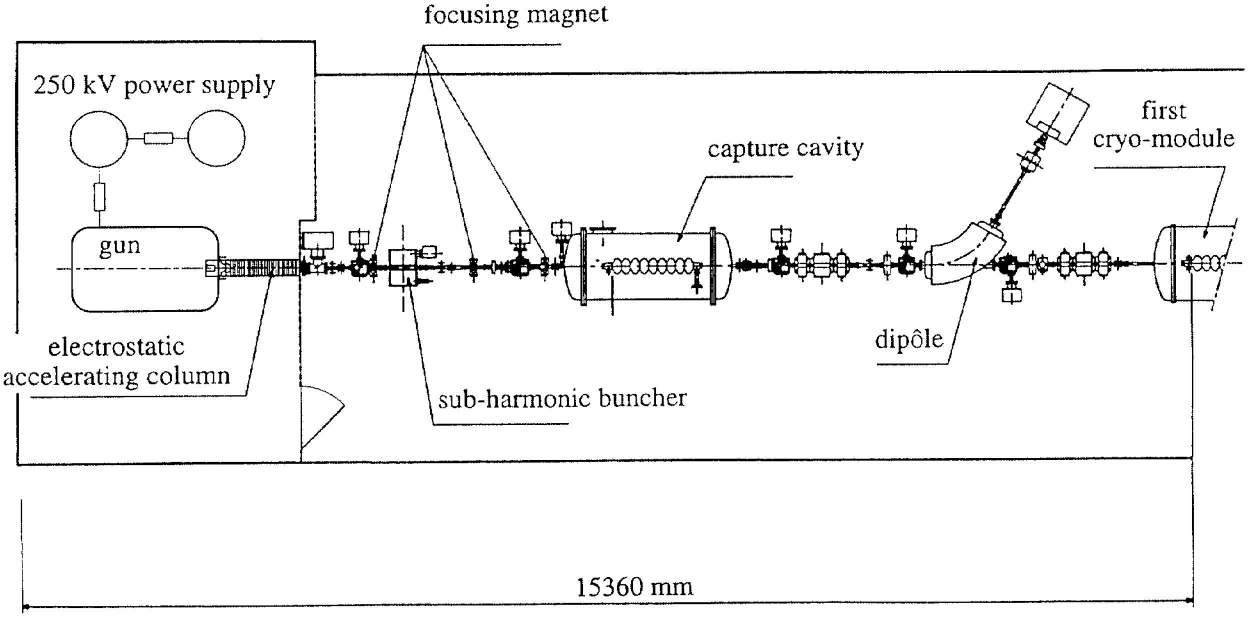

Figure 1. Schematic Layout of TTF Injector.