STATUS OF THE TTF LINAC INJECTOR

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Abstract

The TESLA Test Facility linac injector is currently under installation at DESY. The front end of the injector, consisting of an RF modulated thermionic electron gun, an electrostatic accelerating column, and solenoidal focusing transport line (along with its associated diagnostics) has already been tested in France. Other key components of the injector such as the pre-bunching cavity, superconducting "capture" cavity and cryostat have been tested individually. The results of these tests will be presented and the status of the installation at DESY will be described.

Introduction

The TESLA Test Facility injector essentially consists of: (i) a 250 keV electron source, (ii) a beamline containing a 216.7 MHz sub-harmonic bunching (SHB) cavity, solenoidal focusing elements, and beam diagnostics, (iii) a cryostat housing a 9 cell, 1.3 GHz superconducting cavity, (iv) a triplet magnet associated with an OTR diagnostic which will allow the accelerated beam emittance and bunch length to be determined, (v) a 1 T dipole magnet which can be used to bring the beam onto an analysis line for measurement of the beam energy spread (so verifying the correct adjustment of the RF cavity phases). When the beam is not deviated it passes through a second triplet which, along with the one mentioned above, can be used to match the injector beam to the linac, (vi) a 3 m transport line containing various diagnostics, in particular three different beam position monitor (BPM) designs (two of which will be provided by DESY-Zeuthen). For convenience we refer to parts (i) through (vi) as sectors 100 through sector 600.

The Electron Source and 250 keV Beamline

Figure 1 shows a schematic of sectors 100 and 200 (the pre-injector). The source consists of a 30 kV thermionic gun followed by an electrostatic column to increase the beam energy to 250 keV. Tests of the electron source and the beamline have been performed in France before shipping the pre-injector to DESY. These measurements concerned essentially the transverse beam dynamics and so the SHB cavity was not mounted during these tests. A report on this work can be found in [1]. Briefly, the gun was operated at its nominal settings as given in Table 1.

Table 1
Pre-Injector Characteristics

Beam voltage	250 kV
Average current	8 mA
micropulse repetition rate	216.7 MHz
macropulse repetition rate	10 Hz
micropulse width (at base)	640 ps
macropulse width	800 µs
normalised RMS emittance	3 mm-mrad

The various diagnostics on sector 200 were successfully tested along with the regulation of the beam optics. Having measured the beam emittance it was possible, by using various measured beam profiles, to calculate the envelope of the

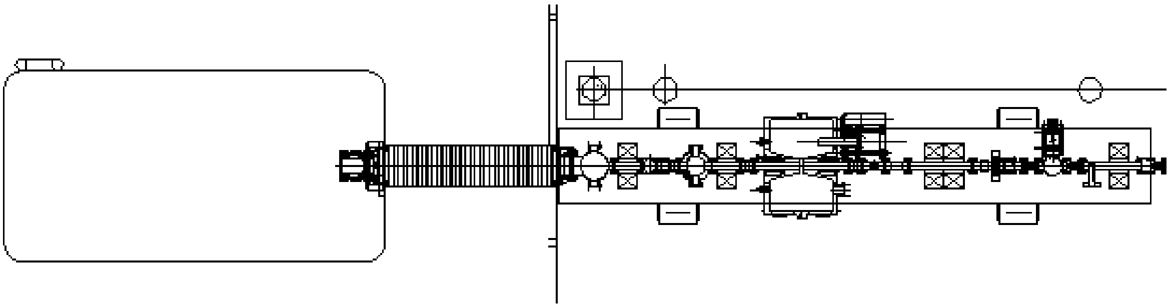

Fig. 1 Schematic of electron gun and 250 keV beam line.

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beam along the beam line. Such calculations indicated that the beam leaves the electrostatic column with a radius (2 rms) of 12 mm and divergence of 7 mrad. Recent calculations of the transport inside the electrostatic column are in excellent agreement with these values (Figure 2).

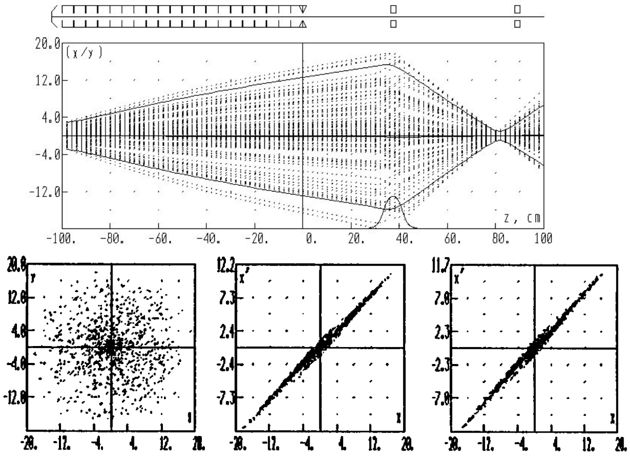

Fig. 2 Beam envelope calculated through electrostatic column and past the first lens.

In December of last year (1995) the pre-injector was dismantled to be shipped off for installation in DESY the following January. By the end of February the pre-injector had been completely re-mounted along with the SHB cavity and was ready for tests with beam.

The SHB is a single re-entrant cell with a transit-time corrected R/Q =130 Ω. The unloaded Q of the cavity with all its coupling loops and tuning plungers in place is measured to be 20,600. A nominal 50 kV is required across the buncher gap to provide the desired pre-bunching before the beam enters the superconducting "capture" cavity. For this we require 400 W in the cavity which is supplied from an amplifier capable of furnishing 2 kW. The cavity had already been conditioned to full power but it has been tested with beam for the first time at DESY.

Beam loading signals in the cavity (with no external RF power), measured via a small coupling loop (-40 dB), correspond well to the low power measurements of shunt impedance. A view screen mounted on sector 200 shows that the transverse beam size changes as a function of the phase of the cavity, indicating that the SHB has a net focus effect on the non-relativistic beam (v/c = 0.74). Tests of the cavity feedback systems and tuner plungers show that they work as foreseen.

The Control System. The injector control system is built from EPICS (Experimental Physics and Industrial Control System) software tools. EPICS was developed at the Los Alamos and Argonne National laboratories and is well suited for accelerator applications. The principal components of EPICS are: A Unix based station or Operator Interface; VME crates or Input-Output Controller; Local Area Network (Ethernet using the TCP/IP communication protocol). The application software for the gun, sub-harmonic buncher, beamline magnets, diagnostics, timing system as well as special tools (e.g. for saving/restoring machine settings) etc. are all running satisfactorily.

The capture cavity

Sector 300 contains the capture cavity which is the first cryogenic device on the TTF linac. Following the pre-bunching on the 250 keV beam line, it accelerates and further bunches the beam before it enters the first cryomodule. The cavity is a standard TTF niobium cavity, fabricated by CERCA S.A. (France), which has undergone the normal treatment and preliminary tests at DESY before being mounted in the cryostat.

During the first series of tests in a vertical cryostat, using High Peak Power (HPP) processing, high field values ($E_{acc} = 21$ MV/m) and good quality factors ($Q_0 = 2 \times 10^{10}$) were obtained. Following these tests the cavity was completely equipped with its helium tank, cold tuner and couplers. This assembly phase takes place in the clean room with intermediate chemical polishing and high purity pressurised water rinsing. A test with the helium tank and HOM couplers was performed in a horizontal test cryostat (CHECHIA) at DESY giving $E_{acc} = 18$ MV/m and $Q_0 = 2 \times 10^{10}$ at maximum field, without electron emission. The nominal beam energy required from the capture cavity is 10 MeV.

The final tests with the main coupler (which was built by FNAL) have shown that the assembly phase was completed with good clean conditions maintaining the performance of the cavity at its high level [2]. After some conditioning period of the main coupler a maximum power of 400 kW, during pulses of 1.3 ms, was applied to the coupler with the cavity detuned. With an external Q of 3×10^6 and a tuned cavity an incident power of 200 kW was reached. The onset of electron emission in the cavity was measured at $E_{acc} = 22$ MV/m. A precise RF measurement was performed for $E_{acc} =$ 16.9 MV/m, showing an amplitude stability of < 0.3% during the pulse and a phase stability < 0.5°. In parallel the capture cavity cryostat (CRYOCAP) was tested using a "dummy" cavity with a special cryogenic interface box [3]. Commissioning of the cryostat at 1.8 K and first measurements of the static losses were obtained during a series of tests performed at the IPN, Orsay. After some improvements of the thermal contacts which allow a faster cool down procedure, the nominal temperature was reached and the level in the helium vessel was precisely regulated. The total static losses (helium vessel, cryogenic interface box and transfer line) were 2.9 W. The helium vessel contributes 1.6 W but this does not include the losses of the RF cables, the main coupler and the beam tubes which are mechanically connected to the 300 K vacuum vessel (through the 70 K shield). These elements must add some additional loss.

At the beginning of July 1996, the cavity was mounted into the cryostat. All the equipment is now assembled including a special beam position monitor located at the cavity output which must operate at low temperature. After the final cryogenic test of the completely equipped cavity an RF test with the dedicated klystron, driven by the amplitude and phase control systems will be performed at the CEA laboratory in Saclay.

The provisional beamline. In order to benefit from a delay in the installation of the capture cavity cryostat we have mounted a provisional beam tube in the space separating sectors 200 and 400. The beam tube has two small lenses mounted on it which allows the beam to be transported to a viewscreen on sector 400. The interest in this provisional line is two fold;

(i) the beam passes through two toroidal current monitors, one on each sector. As differential current measurements between such monitors will be used to detect beam losses in the injector and linac [4], the provisional beamline allows us to test the electronics of this differential protection (DP) system prior to the installation of the superconducting cavity. Beam losses between the two toroids are provoked by scraping the beam on a collimator (ϕ = 15 mm) mounted downstream of the beamtube;

(ii) by placing a button electrode BPM on the beam tube it is possible to monitor the micropulse width of the bunch as it passes the BPM by observing the signal induced on one of the electrodes using a fast oscilloscope. Thus we can roughly adjust the phase of the SHB by looking for a reduction in the bunch length as a function of the cavity phase.

The DP system exists in both fast (FDP) and slow (SDP) versions. In the fast version the toroid signals are sampled at a rate of 100 kHz and if a difference exceeding 500 μA on three successive samples is detected then the gun is tripped off. To prevent a continuous undetected loss of 0.5 mA, the SDP compares the integrated signals during the beam pulse. If a net charge loss corresponding to 100 μA × 800 μs is exceeded then, again, the gun is tripped off. To adjust the optic of the machine for the tests of the DP it was necessary to de-tune the SHB so that beam loading effects, coupled with an off-centred beam, would not diminish the signal seen on the second toroid (once the optic is correctly regulated it is possible to tune the cavity and then "fine-tune" the magnetic lenses to achieve 100% transmission between the two sectors. Subsequent tests of the SDP and FDP showed that it functions correctly.

The tests of the pre-bunching were made using a BPM mounted at the location which would normally correspond to the first iris of the capture cavity. PARMELA simulations indicate that, for the nominal buncher voltage and optimum phase, it is possible to produce a bunch of width 53 ps (25° at 1.3 GHz) at this point. This calculation assumes that one produces a bunch of 640 ps from the gun. In practice we measured a beam of 700 ps at the output of the column. The smallest pulse width measured at the bpm is 220 ps after correction for the response of the monitor (the smallest pulse we can resolve is approximately 130 ps). Although a careful variation of cavity phase was made it is not sure that the RF amplitude setting corresponded exactly to the one used in the PARMELA calculation. Further measurements of this type will performed later this year.

Sector 400

Sector 400 was installed in the DESY tunnel last February and all the components for this sector have been delivered. These include, (a) average current and BPM monitors, to check that the beam is transported cleanly through the capture cavity, (b) the first triplet for matching the beam to the main linac, as well as providing a variable focusing element for measurements of the transverse profile at 10 MeV. An alignment mirror is mounted on this section to be used in conjunction with a small He-Ne laser. An optical transition radiator will be used to make emittance measurements. As the total width of the 10 MeV micropulse is calculated to be of the order of 7 ps it is foreseen to perform bunch length measurements using a streak camera. An optical bench will be placed adjacent to this sector for these measurements.

The Beam Analysis Line

A 60° bend angle dipole will be used to bring the beam onto this analysis line to regulate the RF phase by minimising the beam energy spread. The horizontally dispersed beam will be measured using an SEM-grid mounted in the horizontal focal plane of the dipole. A large retractable OTR radiator in the vertical plane will allow one to verify that the beam is well centred in the beam tube. DP monitoring will also be performed on this line although the larger beam size necessitates the use of a larger toroid (CF100 rather than CF35). The undeviated part of this sector contains the second triplet for matching. All the components for this sector are at DESY although the OTR, SEM-grid and a beam dump remain to be mounted.

Sector 600

Sector 600 is the last beam transport section before the first cryomodule. Consequently it contains a number of beam diagnostics and steering devices to verify that the beam is well centred before injection into the linac. The sector contains a retractable Faraday cup which can be inserted while the injector optics are regulated. This sector will be used to test the performance of a various BPM's with a view to their application in future linacs. The components for this sector are currently being mounted on their support girder in a clean room at LAL. The sector will be ready for delivery to DESY at the beginning of September.

Acknowledgements

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References

[1] J. Fusellier et al., "First Tests of the 250 keV Electron Source and Beamline for the TELA Test Facility Injector" to appear in the Proceedings of the 5th European Particle Accelerator Conference (Barcelona), 1996.

[2] W.D. Möller and M. Pekeler, "Measurements of TESLA Cavities for TTF", to appear in the Proceedings of the 5th European Particle Accelerator Conference (Barcelona), 1996.

[3] S. Buhler et al., "Status Report of the TTF Capture Cavity Cryostat", presented at the CEC/ICMC Conference (Columbus, Ohio), July 1995.

[4] J. Fusellier and J.M. Joly, "Beam Intensity Monitoring and Machine Protection by Toroidal Transformers on TESLA Test Facility" to appear in the Proceedings of the 5th European Particle Accelerator Conference (Barcelona), 1996.