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Abstract

A 500 MeV, 1.3 GHz superconducting linear accelerator is being studied and built to serve as a test facility for the TESLA linear collider project. The phase 1 injector, having an energy of 8 - 14 MeV and an intensity of 8 mA with a high duty cycle (800 microseconds, 10 Hz repetition rate), consists of a 250 keV electron gun, a 216.7 MHz sub-harmonic buncher and a superconducting capture cavity at the main linac frequency. The main characteristics (intensity, position, emittance, bunch length, energy spread) are to be measured using different techniques. A particular effort will be made on the use of optical transition radiation (OTR) for the determination of the transverse beam emittance as well as the bunch length. The injector, involving, the participation of three French laboratories (LAL, CEA/DAPNIA, IPN), will be tested partly in France (Orsay-Saclay) and then completely at DESY (Hamburg).

1. INJECTOR DESCRIPTION

The TTF linac injector can be conveniently divided into 5 sections; (i) a 250 kV electron source and its associated power supply, (ii) a 250 keV electron transport line, (iii) a superconducting RF "capture cavity" to bunch and accelerate the incoming beam to energies of 8 to 14 MeV, (iv) a beam analysis station to measure the properties of the accelerated beam, and (v) a high energy transport line to match the beam to the TTF linac.

As the TTF injector has already been described elsewhere [1,2,3] we will give only a brief description of each of these sections before describing in more detail the diagnostics which will be used on the injector. Table 1 shows the main specifications for the injector. A brief description of the TTF linac can be found in reference 4.

Table 1
Specification of the TTF Injector

Beam energy	> 8 MeV
Average current	8 mA
Pulse length	800 μs
Bunch length (rms)	1 mm
Energy spread (rms)	< 1%
RMS emittance	10 mm-mrad
Repetition rate	10 Hz

1.1 *The Electron Source and Power Supply*

The injector employs a 250 keV electron source in which the electrons are first accelerated to a nominal 30 keV in a conventional thermionic triode gun before receiving the additional energy by acceleration in a 90 cm long electrostatic column. Further details of the 30 kV gun can be found in a companion paper [5]. The electrostatic column is a commercial tube employing a series of metallic field-grading electrodes interspersed by glass insulators glued to the electrodes. The gun and the column are fed by individual power supplies, 40 kV for the former and 300 kV for the latter. To obtain a stable voltage during the 800 μs macropulse the column is powered via a 33 nF capacitor. Measurements of the long term voltage stability show the variations in the power supply are inferior to $1\text{x}10^{-4}$. The entire power supply equipment, which was constructed by Sefelec, has been tested to full voltage. The column-gun arrangement is pumped via a 200 l/s pump at the outut of the column. The vacuum conductance of the column limits the pumping speed at the gun to 35 l/s. Following baking of the gun (80°C) and the column (60°C - limit recommended by manufacturer) the base pressure in the column is $4\text{x}10^{-9}$ mbar. Modulation of the gun is obtained by applying a train of -100 V, 1 ns pulses to the cathode from a wide-band amplifier. The input pulse to the amplifier can be varied in repetition rate from 217 MHz down to 1 MHz. The amplifier (Nucletudes, France) and its associated electronics has been tested into a dummy load and performs according to specification.

1.2 *The 250 keV Transport Line*

Along with the diagnostics (described below) the main elements of the 250 keV line consist of 4 shielded solenoidal focus lenses, and a 216.7 MHz sub-harmonic pre-bunching cavity. The lenses, required to transversely confine the beam during transport to the capture cavity, each provide an integrated strength of $8\text{x}10^{-5}$ T^2m over an active length of 9.4 cm and with a peak field of 350 Gauss. One of the four lenses is constructed as a 'double lens', i.e. two lenses with their magnetic fields in opposing directions. This means that there is no net rotation for the beam on passing through the lens and thus it can be conveniently used for beam emittance measurements. Each lens (purchased from Sigmaphi) incorporates a pair of horizontal and vertical steering elements in which the conductors are drawn onto printed circuit boards mounted inside the solenoids. The sub-harmonic bunching (SHB) cavity is a single re-entrant cell fabricated in stainless steel. To reduce the cavity RF losses the internal surface has received a thin (40 µm) deposition of copper. The cavity is powered by a 2 kW RF amplifier capable of delivering 5 ms pulses at 10 Hz. The amplifier (RFTS, Bordeaux), which was specified to have phase stability of 0.5° and an amplitude stability of 0.5% during a 1 ms pulse has been fully tested and shown to meet its specifications. The cavity has been conditioned with full RF power and bench measurements have confirmed the computed shunt impedance and unloaded Q of the cavity (R_s = 3 MΩ, Q_0 = 22000). With the exception of the SHB all elements on the 250 keV beam line have been mounted on a common girder and the girder has been installed at the output of the high voltage column. At the time of writing tests of the 250 keV beam are planned to commence at the beginning of May 1995.

1.3 *The Capture Cavity*

After the SHB further bunch compression is performed by a superconducting (SC) cavity. The SC cavity is a standard niobium, 9 cell, TESLA cavity, fabricated by CERCA S.A. (France). After hydroforming the half cells, heat treatment in a vacuum furnace was performed at Saclay (1300°C for 1000 minutes) which improves the residual resistivity ratio (RRR) of the niobium to an estimated value of 360. Following this treatment, complete electron welding of the cells, coupler ports and helium tank connecting flanges was accomplished. The chemical polishing treatment of the cavity internal surface (105 µm) was followed by High Pressure Water Rinsing (100 bar) at DESY.

The cavity was tested at DESY in a vertical cryostat equipped with a special coupler and waveguide transition for RF conditioning using High Peak Power (HPP) processing. Initial HPP in LHe at 4K was applied to the cavity with 1 MW peak power RF pulses at a repetition rate of 2 Hz and progressively increasing pulse lengths (50 µs, 100 µs, 200 µs). During this first experiment the accelerating field reached 21 MV/m with a $Q_{ext} = 10^6$. After cooling the helium bath to 1.8 K further HPP conditioning was applied culminating in a maximum accelerating field of 23 MV/m with a 300 µs RF pulse. Measurement of the Q vs E_{acc} at 1.8 K in cw mode shows a very good low field Q_0 (1.4×10^{10}) and absence of electron emission, however the accelerating field was limited to 14.5 MV/m by a quench. In conclusion the fabrication methods and the treatments were validated giving very good results for this cavity so allowing its mounting into the capture cryostat. Simulation studies of the injector show a large tolerance for the acceptable accelerating field (8 - 15 MV/m) in order to achieve the required electron beam specifications at the entrance to the first cryomodule.

The cold tuning system is now ready to be mounted in the cavity. It was assembled on a TESLA cavity and tested at room temperature giving a frequency tuning range of ± 470 kHz. A complete mechanical test, including the stepping motor, was performed in a LN_2 bath.

The main parts of the capture cryostat are now fabricated and the assembly has started. A special interface cold box is under construction in order to perform a complete test of the cavity with its coupler at the nominal operating conditions, both with cryogenic and RF power.

The capture cavity klystron has been succesfully tested to 300 kW peak power with RF pulses of 2 ms (10 Hz repetition rate). The modulator exhibits a plateau stability of 0.1% during the pulse. The phase and amplitude control loops are now constructed and the design concepts were succesfully tested in the MACSE facility at Saclay with the nominal pulsed condition of the TTF linac.

1.4 *The Beam Analysis Line*

ln order to verify the beam parameters after acceleration in the capture cavity, and to allow regulation of the RF phases, a beam analysis line is installed down stream of the capture cavity. The high energy beam is deviated by a dipole magnet having a bend radius of 700 mm and a bend angle of 60°. Vertical edge focusing is provided by introducing a wedge angle of 18.24° at the exit and entrance faces. The resulting horizontal focal plane is 1242 mm downstream of the exit face, and consequently energy spread measurements will be made in this plane as described below. The maximum allowable field in the magnet is 0.1T, permitting electrons of energies upto 20 MeV to be measured.

1.5 *The High Energy Transport Line*

The principal elements of the high energy transport line, again with the exception of the diagnostics described below, consist of a pair of quadrupole triplets which will be used to transport the beam emerging from the capture cavity to the first cryomodule of the TTF linac. Again, the triplets incorporate steering elements to properly centre the beam at the input to the first cryomodule. At a later stage we plan to install a magnetic chicane on this line to permit experiments with off-axis beams in the linac. X-ray diodes, situated close to beam collimators, will indicate the presence of beam losses when tuning the injector. While tuning, the beam will be stopped in a cooled Faraday cup capable of handling the 1 kW average beam power.

2. BEAM DIAGNOSTICS

In order to measure and check the beam characteristics appropriate instrumentation is installed along the linac. On the 250 keV beam line, up to the first cryomodule, numerous monitors are provided due to the necessity to verify and, if possible, improve the initial beam characteristics. Non destructive monitors are used for beam intensity, position and RF phase but all profile monitors are destructive.

2.1 *Intensity and Position Measurements*

The beam pulse at the gun exit will be checked with a capacitive pick-up made from an alumina ring with a copper deposition on its inner and outer surfaces. The capacitance is 120 pF. Current monitors using toroids, placed before and after the capture cavity permit beam intensity monitoring and allow beam losses to be detected to provide a "trip" signal to turn off the gun.

Beam position monitors (BPM's) of the "button electrode" type have been constructed to monitor the beam position throughout the injector. An additional electrode on one BPM allows a measurement of the RF phase of the beam with respect to the master oscillator phase. The beam centroid is evaluated using the signals delivered by four electrodes. These signals are first filtered and then RF multiplexed before being treated in a single analogue electronic channel so as to avoid discrepancies due to different gains, bandwidths or zero offsets between four different channels. Results concerning the beam position are represented on a graphic page using written indications (position in mm) or bargraphs. Acquisition and timing procedures are monitored through a VME card. Time shuttering inside the macropulse is forseen. This will allow a sharper analysis of the beam position.

2.2 *Beam Profile Measurements*

The 6-D emittance is obtainable through transverse and longitudinal profile measurements. Developments in optical methods and of the associated software tools make them preferable for this task [6]. Nevertheless, more classical methods using, for example, secondary electron emission are also considered.

Transverse Beam Profiles

Secondary electron emission with SEM-grids and optical transition radiation with aluminium foils and luminescent screens are used. Retractable aluminium oxide screens with a thin, transparent, deposition of indium oxide are used before and after the capture cavity to get approximate information on the beam dimensions. Quantitative information on the beam profile is obtained by an SEM-grid placed between the SHB and the capture cavity. The low beam energy (250 keV) implies short stopping ranges and high energy deposition in the grid material. Therefore titanium strips of only 12 µm thickness were chosen. To permit high enough resolution and measurement range, an SEM-grid with 32 strips of 300 µm width and 400 µm separation has been constructed. Integrators with LF356 op-amps are connected to the strips. An adjustable gain amplifier is added in each channel. Digitisation is ensured via a MAX255 circuit. Each of these modules has 8 sample-and-holds with a multiplexer, an 8 bit ADC and an 8 bit x 8 channel memory. Data treatment is done with standard VME. Beam profiles are displayed on a monitor and the corresponding widths (FWHM, RMS...) sent to a data base. Due to space-charge effects at this energy an appropriate procedure is necessary for the emittance calculation. It uses the integration of the Kapchinsky-Vladimirsky envelope equation,

$$R'' + K(z)R - 2I/I_A(\beta\gamma)^3R - \varepsilon^2/R^3 = 0$$

This equation is integrated succesively for n different settings of a magnetic focusing lens placed before the SEM-grid. The calculated radii are then compared to the measured ones and a least squares fit method gives the value of the emittance, radius and divergence of the beam upstream of the magnet. The Twiss coefficients are then derived and the ellipse constructed and displayed [7]. A 100 ns gating system allows emittance analysis inside the macropulse.

An SEM-grid made of 40 tungsten wires (20 micron diameter, 2 mm separation) placed in the horizontal focal plane of the bending magnet of the injector analysis line will provide energy spread measurements with a dispersion of 16 mm/%. Profiles and associated widths are processed as described above. After acceleration in the capture cavity, the transverse beam profile will be measured using OTR. N profiles, corresponding to N different settings of the quadrupole triplet upstream will permit the emittance to be calculated using the "method of three gradients" and a least square fitting routine. An intensified CCD camera permits time resolved emittance measurements in the macropulse with a minimum time window of 100 ns. The beam divergence at the OTR location will be obtained by collecting part of the optical image after a beam splitter. This will be done by placing the CCD camera in the focal plane of the lens. A digitising card (IPP/ELTEC) working on a VME standard will allow digital conversion, on 8 bits, of 4 cameras at video standard CCIR or EIA. An interlaced mode, however, is not allowed here. Image storage will be done in a 1 Megabyte memory zone. External synchronisation for the acquisition is used. Gain and offset at the entrance of the ADC is programmable. A video output is used to obtain the beam spot. A C-library is connected to this card. The use of numerical filters, mathematical transforms and histogram construction is available by this means. Moreover, this library supports the hardware functions. It works under OS9 and some modifications have made it usable under LynxOS and VXWorks.

Longitudinal Beam Profile

A second beam splitter will take part of the optical light to a streak camera (ARP-RGM-SC1) having a resolution of 3 ps. Bunch lengths will thus be determined.

3. SUMMARY

A brief description of the status of the TTF injector has been given. The electron source and the 250 keV beam line are essentially complete and beam tests will begin soon. A capture cavity with the desired RF performance has been produced and its cryostat is under fabrication. The klystron has been tested to full power. The magnets for the high energy beam line have been specified and are on order from industry.

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