

FIRST BEAM TESTS OF THE TTF INJECTOR

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Abstract

Following tests of the various sub-assemblies at Saclay and Orsay, installation of the entire TESLA Test Facility Injector was completed in Hall 3 at DESY in December 1996. The first phase of operation employs a 250 kV thermionic electron source providing an 800 μ s train of bunches, each containing 37 pC, and followed by a 216.7 MHz pre-bunching cavity. Subsequent bunching and acceleration is achieved using a standard 1.3 GHz superconducting 9 cell TESLA cavity operated in pulsed mode (10 Hz). Prior to injection in the main linac, the beam parameters are verified using a spectrometer consisting of a dipole magnet and SEM profile monitor. Once the beam is adjusted it is transported to the linac using an optical matching system employing two triplets. We present results of the first beam tests of the completed injector which took place early in 1997.

1 INTRODUCTION

The TESLA Test Facility (TTF) is a high duty cycle superconducting (SC) electron linac and its associated infrastructure. The L-band (1.3 GHz) linac will be used as a test bed to validate the principle of a SC e^+e^- linear collider (TESLA). TTF is currently under construction by an international collaboration at the DESY laboratory (Hamburg). Within the collaboration the three French laboratories named above have undertaken the task of constructing a pulsed SC injector for the linac. Descriptions of the linac and its injector can be found elsewhere [1,2] and here we will restrict ourselves to a report of the first beam tests with the complete injector which took place in January/February of this year. Tight scheduling of the installation of the first linac cryomodule meant that only four weeks of operation were available for these tests.

2 THE CAPTURE CAVITY

The capture cavity is a standard 9 cell TESLA cavity fabricated by CERCA. Its cryostat (CRYOCAP) was built and tested by the IPN-Orsay. Cryogenic tests and tests of the analogue feedback loops were performed at Orsay and Saclay. The feedback system is described in a companion paper [3]. It allows the cavity to operate with an amplitude stability better than 0.1% and a phase

stability of less than 1 degree. Although the cavity has operated at 18 MV/m without field emission (FE) in a horizontal cryostat, we restricted our tests to 14 MV/m. This was due to the FE now seen at the latter gradient which results in a reduction of the Q factor to 5×10^8 and a high X-ray level around the cryostat. No high power RF processing was applied following the installation. During operation at 14.8 MV/m we measured a dark current level of 300 nA on a Faraday cup ($\phi = 25$ mm) placed 1.15 m upstream of the first cavity iris.

3 BEAM ACCELERATION TESTS

The "pre-injector" consists of a 250 keV electron source, a 216.7 MHz sub-harmonic buncher (SHB) and four solenoidal focusing elements. Tests of the pre-injector have been reported previously [4]. The SC 'capture cavity' is used to provide further longitudinal bunching and to accelerate the beam to the desired energy (typically 8 to 12 MeV). Tuning of the injector is achieved by varying the amplitudes and phases of the SHB and capture cavity. The criteria for correct tuning during these tests has been the achievement of a minimum in the beam energy spread while ensuring maximum current transmission along the injector. The energy spread is measured using a spectrometer arm consisting of a magnetic dipole and an SEM-grid to measure the horizontally dispersed beam profile [5]. The current is measured with the use of toroidal current monitors. Four such monitors are mounted on the injector. Toroids #1 and #2 are at the entrance and exit respectively of CRYOCAP, #3 is on the spectrometer arm (upstream of the SEM-grid) and #4 is at the end of the injector.

3.1 Beam transmission measurements

The required current for TTF is 8 mA during an 800 μ s macropulse at 10 Hz repetition rate. As the average beam power in the TTF linac is high, a differential protection system, based on the toroidal current monitors, is used to protect the machine against beam losses [6]. This system cuts off the gun if an integrated charge loss of 80 nC is detected between successive toroids during the macropulse. This corresponds to an average current loss of 0.1 mA during an 800 μ s pulse (or 1.25% of the 8 mA beam). The same system is employed on the injector and

thus setting up the injector requires careful adjustment of the RF cavities and magnetic elements. Consequently, the injector is tuned using a "short pulse mode" of 30 μ s duration. For the commissioning tests the loss threshold for the long pulse or "un-restricted mode" was increased to 200 nC between toroids #2 and #3.

With the beam well centred at the entrance to CRYOCAP one quickly obtains 100% transmission of 8 mA through the capture cavity and upto the end of the injector. The beam energy is measured using the spectrometer while the cavity gradient can be estimated from the incident power. The ratio of the energy gain to field gradient is consistent with calculations [7]. Typically we obtain 11 MeV for 12.5 MV/m. Figure 1 shows signals from the first three toroid monitors superimposed. The SHB uses a feedback loop to correct the phase and amplitude changes induced by beam loading. Left uncorrected, an 8 mA beam would induce a phase shift of 18° of the 216.7 MHz. In practice, the feedback system is capable of compensating for the beam loading with the exception of the first 8 μ s during which a residual phase shift of < 5° is present. This effect explains the difference in current level between the first two toroids and the dispersed beam on toroid #3 during the pulse rise time (Fig. 1, left). This can be cancelled by applying a "phase-jump" to the cavity with a sense opposed to that induced by the beam (Fig. 1, right).

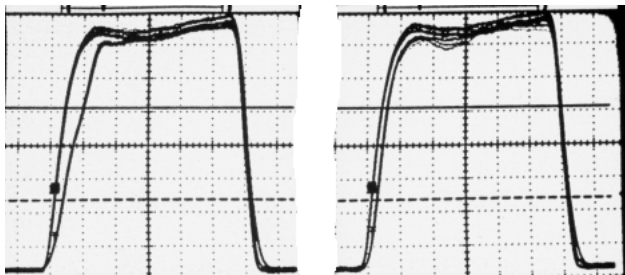


Figure 1. 7 mA, 30 μ s current trace from the first three toroids; (left) without phase jump, (right) with phase jump (see text for details).

3.2 Energy spread measurements

The spectrometer dipole produces a dispersion of 16 mm/% of energy spread at the location of the SEM-grid. The grid contains tungsten wires of 20 μ m diameter spaced at 2 mm intervals and is intended for use with the full pulse width. The first tests with 8 mA of accelerated beam showed that the transmission to the beam analysis line was only 90%, insufficient for switching to the long pulse mode. In view of the limited time available for injector tests, rather than investigating this loss in detail, we reduced the current to 6 mA for which the transmission to the analysis line was 97%, just enough to operate in long pulse mode and thus to investigate the distribution in energy. Figure 2 shows the output of the grid for an 11 MeV beam. The RMS energy spread is 68 keV. Several measurements made for different current levels (from 2 to 6 mA) show that the fractional RMS energy spread is always inferior to 0.8% when the injector is properly adjusted.

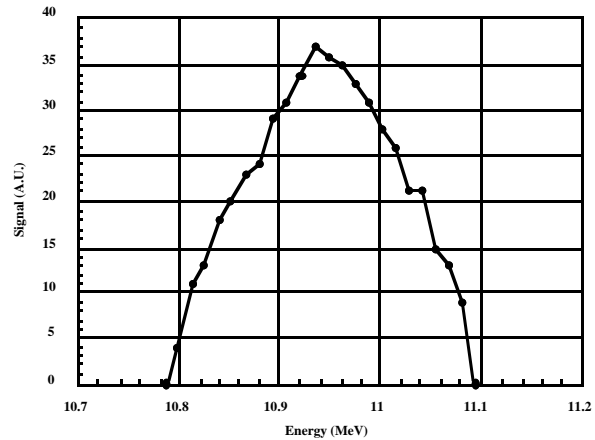


Figure 2. Beam energy distribution obtained on the SEM-grid.

4 EMITTANCE MEASUREMENTS

The transverse emittance has been obtained from measurements of the transverse beam profile using optical transition radiation (OTR). An aluminium foil of 20 μ m thickness is employed as the radiator. Light from the OTR foil is focused onto a gated, intensified CCD camera using a telescope composed of two achromatic lenses with a magnification of 0.5. Data acquisition is obtained by means of a CPU operating in a VxWorks environment. A frame grabber and the camera record signals with an 8 bit resolution. The camera is synchronised to the master oscillator of the injector and the gain and shutter time are controlled by a serial port of the CPU. Acquisition, image processing and statistical analysis are performed using an "in-house" computer program so allowing on-line calculation of the emittance. Fig. 3 shows a typical example of an acquired profile. Emittance measurements are taken with a macropulse of 30 μ s width to avoid damage to the aluminium foil.

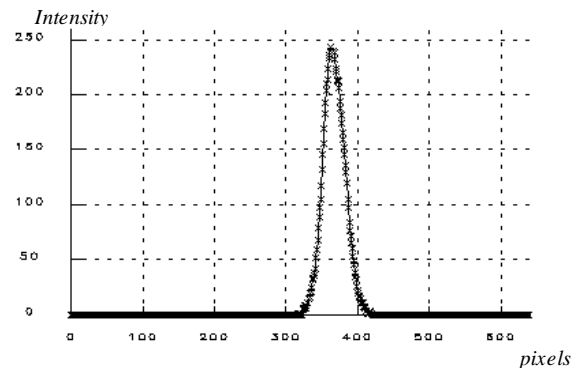


Figure 3. Horizontal profile of the beam from the OTR image. The scale is 37 μ m/pixel.

To obtain the Twiss parameters of the beam we have used the method of "three gradients". The focusing of the beam is varied by means of a magnetic triplet placed

upstream of the OTR foil and the beam profile recorded for each setting. To improve the reliability of the fit between the beam radii and the triplet strengths, ten images are recorded for each of eleven different settings of the triplet. Statistical analysis of the image sets allows the beam radii and the related standard errors to be calculated. The radii are calculated for 50% and 90% intensity contours as well as for the FWHM. These calculations are performed both for the integrated profiles and for the horizontal and vertical profiles through the centre of charge of the beam. All these data are then fitted using an "in-house" chi-square minimisation routine. At our energy and with our experimental layout the approximation of a thin lens for the triplet is not valid. Consequently, we use the real transport matrix values. As well as the emittance, we also calculate the error to the fit, the covariance matrix, the beam matrix coefficients and the chi-square value as a measure of the statistical degree of confidence of the measurement [8]. Emittance measurements have been performed for various beam energies and linac optics. At 10.6 MeV, and with correct setting of the injector optics, the 90% contours give normalised emittances of $\epsilon_x = 16.5$ mm-mrad and $\epsilon_y = 18$ mm-mrad for the horizontal and vertical planes respectively. During the triplet scan, the beam centroid was seen to displace in the vertical direction and so the larger emittance values in this plane may be due to an imperfect vertical alignment of the beam in the triplet. The corresponding figures for the 50% contour are 2.4 mm-mrad and 2.8 mm-mrad. Similar values were obtained for a beam energy of 8.7 MeV. In varying the trigger time and acquisition period of the camera, time resolved measurements of the emittance were also obtained by recording profiles for 1 μ s slices within the macro-pulse. These data show slightly smaller values for the "slice" emittance during the pulse rise-time with stable values found during the flat-top.

5 CONTROLS

The control system for the injector has been described elsewhere [9]. The system is based on EPICS with VME crates for equipment interface and SUN workstations as operator consoles. During the entire commissioning period the controls have been very reliable. Extensive use has been made of the EPICS task to 'save' and 'restore' machine parameters. The operator can create special "parameter" pages which can be assigned to eight encoder 'knobs' allowing analog control of eight parameters and making visible useful information. Binary control, such as the insertion of diagnostics or ON/OFF control of power supplies, is also permitted with these pages.

6 CONCLUSIONS

We have presented results of the first operation of a high field gradient (> 10 MeV/m), pulsed mode, superconducting linac. These tests show that the linac performs as foreseen and that certain specified beam parameters have been met (table 1). The emittance values

are consistent with measurements made on the gun and pre-injector [4,10]. Injector tests will resume in May of this year and the transmission of 8 mA onto the spectrometer arm will be investigated further. In addition, the measurement of the micropulse length will be performed by streak camera analysis of the OTR.

Table 1. Comparison of achieved and specified parameters.

	Specified	Achieved
Energy	> 8 MeV	8 - 13.5 MeV
Current	8 mA	8 mA
Pulse width	800 μ s	800 μ s
RMS energy spread	< 100 keV	~ 70 keV*
RMS emittance	< 5 mm-mrad	< 4 mm-mrad

(* at 6 mA)

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