THE SLS TEST FACILITY – FIRST RESULTS

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Abstract

The SLS test facility is a 50 MeV S-band linear accelerator, consisting of a thermionic RF-gun, magnetic bunch compression (alpha-magnet) and a 50 MeV LINAC. It serves as a testbed for the development of diagnostic devices for the SLS and is capable of providing ultra short pulses for spectroscopic applications. In this paper we report about the comissioning of the SLS test facility and the complete characterisation of the electron beam including current, energy, energyspread, emittance and bunchlength.

1 DESCRIPTION

1.1 RF power source and waveguide network

The gun and the linac are simultaneously powered from a single 35 MW pulsed RF source. It consists of a 3 GHz klystron, TH2100 from THOMSON TTE, whose cathode is pulsed (for 5 μs at 100 Hz, max.) by means of a high voltage modulator which is a replica of the CERN LIL modulators, produced in a collaboration between CERN and PSI [1]. The 200 W RF signal required to saturate the klystron is delivered by a pulsed solid state RF generator (oscillator-amplifier) from MILMEGA.

While the RF generator is connected to the klystron input by means of a coaxial cable, a WR284 waveguide line filled with pressurised (~ 3 bars) SF6 gas is used after the klystron. Ceramic windows isolate the SF6 filled sections from the UHV regions, inside the klystron, the gun and the linac. In between, are inserted bi-directional couplers for monitoring the forward and reflected RF signals at different locations. A circulator protects the klystron against the transitory and stationary reflected power from the gun. A variable attenuator and a phase shifter, located after the power splitter in the gun branch, allows to adjust the relative RF amplitude and phase between the gun and linac inputs. In order to prevent the differential RF phase variations, all the waveguide components are cooled with temperature stabilised water (30 ± 0.1 °C, as for the gun and the linac) flowing in copper pipes braised along their walls

1.2 The electron RF gun and the α-magnet

The electron gun is a prototype of the CERN CTF (CLIC Test Facility) photocathode RF gun which was modified by PSI for use in the thermionic regime [2]. It basically consists of a 1/2 + 1 cell cavity designed to operate at 3 GHz in a TM010-π-mode. The power is fed through a WR284 waveguide which is tangentially coupled to the cells by slits milled along the cavity walls. Each of the two cells are equipped with a plunger tuner and a monitoring pick-up. The gun is cooled with temperature stabilised water (30 ± 0.1 °C) flowing into channels located inside the cavity body.

The cathode was supplied by the company SPECTRA-MAT as a plug-in package, according to the PSI specifications. The emitter of 3.5 mm radius, made of Tungsten impregnated with Barium Calcium Aluminate, is potted into a Molybdenum base which itself contains the heater filament. A thin cylindrical Moly-Rhenium sleeve prevents from excess of heat conduction into the gun wall. The region surrounding the cathode assembly forms an RF choke which presents a low impedance at the cathode plane. Beam dynamic simulations were previously performed using the computer codes SUPERFISH and PARMELA. The results showed that, after minor hardware modifications and optimisation of the operating conditions, the CTF photocathode gun could be converted into an RF thermionic gun capable to generate high brightness electron beams when being combined with an appropriate α-magnet [3,4]. In particular, the computations pointed out that the optimum condition, corresponding to a linear momentum-phase dependence of the electrons at the α-magnet entrance, could be obtained when the peak accelerating field at the cathode was set to 25 MV/m. The maximum electron momentum is then essentially determined by the peak accelerating field in the second cell of the gun (1.9 MeV/c for $E_2 \approx 50$ MV/m, 2.5 MeV/c for $E_2 \approx 80$ MV/m) and the charge per bunch by the temperature of the cathode.

The first experiments were carried out using a Faraday cup directly connected to the gun exit [5]. Bunch charges up to 300 pC were measured with a cathode temperature of about 1050 °C (~50 W heating) and an RF power around 2 MW.

1.3 The LINAC

The linac accelerating structure that we got as a loan from DESY is a 5.2 m long, disk loaded constant gradient TW section, operating at 3 GHz in the 2π/3 mode. One particular feature of this structure is that the last eight cells are coated with an absorber material, forming an integrated collinear load. The achieved energy gain depends on the input RF power and beam current according to the following relation:

$$U\,[\text{MeV}] = 13.13\,(P_{in}\,[\text{MW}])^{1/2} - 54.7\, i_{beam}\,[\text{A}].$$

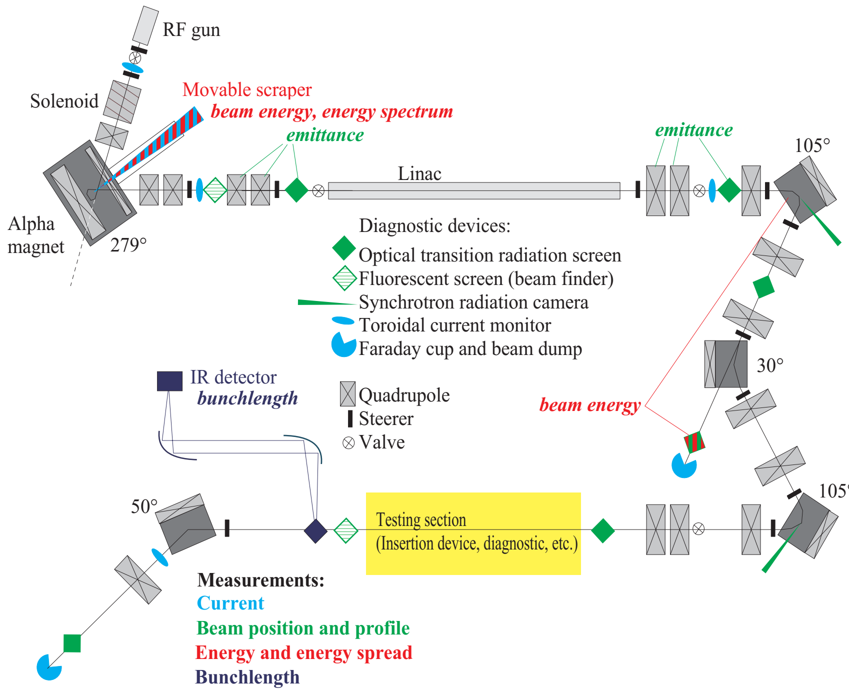

Figure 1: SLS Test Facility: overview and diagnostics

With the relatively low beam current involved during our experiments, the electrons were accelerated up to 50 MeV with less than 17 MW.

1.4 Low momentum (≈ 2 MeV/c) beamline

The α-magnet deflects the beam achromatic by 279° and provides a longitudinal compression of the bunch. It is made from a ½ quadrupole taken from a PSI proton beamline with a mirror plate. It can provide a maximum magnetic gradient dB/dx of 6 T/m. Momentum filtering (elimination of the low energy electrons) is realised by means of a movable collimator inside the α-magnet. A solenoid and 5 quadrupoles provide focussing between gun and linac.

1.5 High momentum (≈ 50 MeV/c) beamline

Three bending magnets form an isochronous 180° deflection in order to fold the accelerator into the limited space of the previously existing building. Two quadrupole pairs allow to vary the longitudinal drift in a range of –30...+7 ps/%·Δp/p, and two triplets before and after the deflection provide a flexible focussing. An empty straight of 3 m length is for installation of the devices to be tested. Eventually a fourth bending magnet guides the beam to the dump [6]

2 MEASUREMENTS

2.1 Emittance

Fig. 2 shows the set-up for determination of transverse beam parameters: The beam spot on an OTR screen is observed by a CCD camera, the image is grabbed by a PC, beam profiles are integrated and beam radii extracted from a Gauss fit. Two upstream quadrupoles are varied to change the beam image and their currents are read from the EPICS database. Backtransformation of a set of beam radii measurements gives the beam parameters at the first quadrupole's entrance with error margins derived from a χ^2-fit demanding for 95% consistency [7]. Table 1 displays the emittance results measured after the α-magnet and after the linac.

2.2 Coherent TR and Electron Bunch Length

In the testing section of the SLS test facility a TR port is dedicated to the analysis of the bunching process through the accelerator and the measurement of the electron bunch length with coherent transition radiation (CTR).

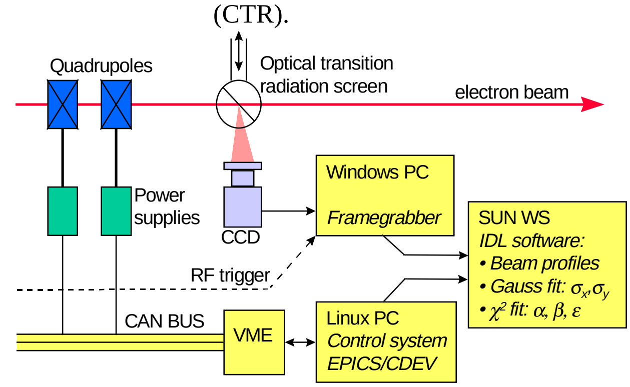

Figure 2: Set-up for emittance measurements

Table 1: Results of emittance measurements

Location	after α-magnet	after linac
Momentum [MeV/c]	1.6	41
Bunch charge [pC]	≈4	1.3
rel. mom. spread [%]	5	0.24
ε_x [mm mrad]	0.46 ±0.10	0.17 ± 0.04
ε_y [mm mrad]	0.23 ±0.07	0.36 ±0.08

CTR is produced at wavelengths, which are in the order of the electron bunch length. In linear RF accelerators the electron bunches are usually a few ps long, which leads to a coherent enhancement of the emitted TR in the far infrared (FIR) and in the mm-range. The total energy radiated by N electrons is then proportional to N^2 and can be expressed as [8]

$$I_{TR} \sim [N + N^2 f(\omega)] I_0 ,$$

with I_0 the energy radiated by a single particle and $f(\omega)$ the so called bunch form factor, which can be expressed through the magnitude squared of the Fourier transform of the mean particle distribution.

In our experiments the FIR light is transported through a vacuum tube (light pipe) out of the linac basement floor to the experimental hall. Two parabolic mirrors (PM) image the TR source point on an optical table, where the integrated radiation intensity is analysed by a pyroelectric detector. For spectrum analysis the CTR is coupled to RF horn antennas, which are connected to filters with calibrated band pass characteristics. The spectral intensity is measured with commercial RF power meters.

In order to verify the coherence of the produced TR, we varied the number of electrons per bunch by changing the temperature of the electron gun. The integrated intensity of the radiation scaled with the square of the bunch charge as it is expected from theory. By maximizing the microwave CTR signal on the pyroelectric detector and comparing the average intensity with and without a band pass filter, which was transparent between 6.5 GHz and 16 GHz, the bunching process through the linac could be optimized. Estimates about the shortest achievable electron bunch lengths could be made under the assumption of a gaussian particle distribution. Fig. 3 shows two measurement points, which are sufficient to determine $\omega_{1/e}$ and thus $\Delta t = 1/\omega_{1/e}$. In this very simple and straight forward experiment we obtained $\Delta t = 5.5$ ps.

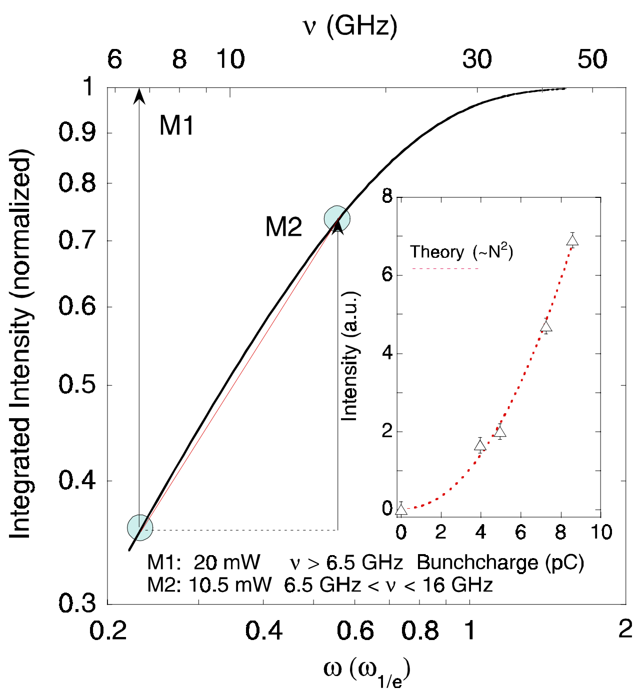

Figure 3: Estimate of the electron bunch length as obtained from a fit to the normalized intensity for gaussian time distribution. Demonstration of square law dependence of the emitted CTR on the bunch charge (inset).

Since we observed that the linac overall performance is sensitively correlated to the integrated intensity of the CTR, the above analysis represents a valuable tool in accelerator diagnostics [9].

In order to obtain more details of the CTR spectrum on the microsecond time scale of the linac macropulse two novel approaches have been evaluated: The reconstruction of the spectrum from the splitting of the RF signal into several bands which will be measured and analyzed in real time and, secondly, for ultimately high time resolution, the so called free space electro-optical sampling technique [10]. The latter technique may allow bunch length determinations even for a single shot.

3 CONLUSION AND OUTLOOK

The SLS test facility is a fully operational 50 MeV linear accelerator with RF gun and electron bunch compression through an α-magnet. It is presently used for development and calibration of diagnostics equipment for the SLS. The characterisation of electron beam parameters during the commissioning phase of the test facility have shown that it provides the opportunity for future short pulse experiments with coherent radiation and even FEL applications are imaginable.

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