COMMISSIONING OF THE 50 MeV PREINJECTOR LINAC FOR THE BESSY II FACILITY

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Abstract

A turn key 50MeV linac manufactured by Thales has been installed at the BESSY II facility. This linac will replace the existing microtron injector in the near future to provide more flexible bunch population patterns for the femto-slicing operation mode and a higher single bunch intensity for Top-Up injection.

INTRODUCTION

In preparation for Top-Up operation at BESSY II, [1], the existing injection system is being upgraded. Here a linac has been commissioned to meet specification, [2]. The two main operation modes; Short Pulse Mode SPM (1 to 5 pulses each 0.35nC) and a Long Pulse Mode LPM (40 to 200ns of total charge 2nC), deliver electron bunch trails to be injected into the booster. Emittance and energy spread measurements have been realised for each of these modes. A summary of the site acceptance test (SAT) measurements are found in Table 1. Final acceptance was on 22 July 2011.

LINAC

A standard Pierce type, DC grid cathode is used as the source of the linac. Here the 500MHz pulsed electrons are accelerated to 90keV. The peak beam current from the gun in SPM is 600mA, and a continual trail of these bunches constitute the LPM.

A series of focusing lenses deliver the low energy beam through the prebunching sections. The first stage being a sub-harmonic 500MHz pill box cavity, where a 25kV modulation is used to bunch the 1ns beam pulse. Next a 3GHz cavity of 10kV modulation bunches one beam pulse (from three) for further acceleration reducing the overall energy spread and the bunch length to ∼60ps. The two prebunchers are used to supply the main buncher, a 22 cell, $\pi/2$ mode standing wave structure. Driven by 5MW (4μs Klystron pulse at 10Hz) RF power, this buncher increases the beam energy to 15MeV using an average electric field on axis of 18MV/m. Surrounding the buncher, shielded solenoids help guide the beam onwards through the structure, and on exit a Glazer lens provides additional focusing. With an on axis maximum magnetic field of strength of 4100 Gauss, the Glazer lens provides sufficient beam focusing to allow the down stream $2\pi/3$ mode traveling wave accelerator to operate without external focusing. This accelerator, a 3.5m long 96 cell constant gradient structure, is driven by 8MW RF power to increase the beam energy to 50MeV and reduce the bunch length to ∼20ps.

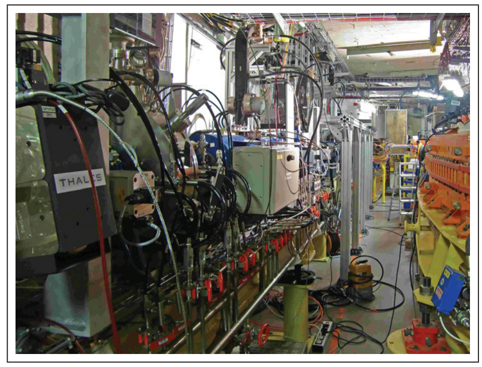

Figure 1: View along the linac.

The single bunch Top-Up operation at BESSY II used for time resolved experiments is limited by the low current of the injector microtron. In comparison the linac will provide a factor 40 times more current per single bunch, enabling fast accumulation of a few intense bunches into targeted storage ring buckets.

Installation

The linac is housed in the existing booster synchrotron bunker. In order to minimise the disruption to ongoing beam-time operation at the facility, the linac was installed through a removable wall during shut down. The in-situ welding repair due to a water leak in the main accelerator vacuum chamber delayed the installation by 5 months. Figure 1 highlights the limited amount of space available in the bunker, the distance between the booster magnet and the linac structure is under a metre.

The new transfer line was designed in house and the magnets manufactured at the Budker INP. This optic allows for the commissioning of the linac, then at a later date, injection into the existing optic via a shared magnet.

Diagnostics

The site acceptance tests for commissioning were carried out by Thales under the supervision of HZB staff. Numerous RF and beam diagnostics are implemented along the linac structure in order to help deliver the beam.

Low level RF from the source, coupler and feed-back signals, were used to optimise the delivery of the Klystron

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Table 1: Measurements of the Bunch Modes during Commissioning, 12 Hour SAT Average

	Spec. SPM	**Measured**	**Spec. LPM**	**Measured**
Energy (MeV)	50	50.9	50	50.6
Transmission (%)	61	64	68	88
Charge (nC)	0.35	0.34	2.00	2.15
Energy Spread (% rms)	0.40	0.24	0.40	0.39*
Norm. Emittance H, V (π mm mrad)	50, 50	38.6, 32.7	50, 50	12.2, 10.7

* before accelerator temperature adjustments

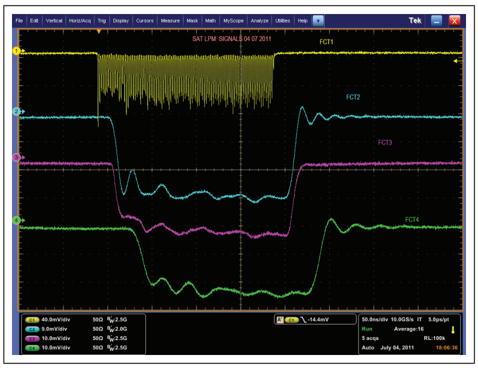

Figure 2: FCT measurements along the linac.

power to the cavities. Over the course of 2 weeks the RF power was ramped to the required level for a 50MeV beam.

Four Fast Current Transformers (FCTs), were used to commission for maximum transmission the two operation modes at different bunch lengths, Fig. 2. FCT1 curve without a low pass filter shows the LPM bunch structure.

The two main beam characteristics; emittance and energy spread, were measured in the straight and bending branch of the transfer line respectively. Digital monitors in each branch provided online diagnostic.

The commissioning principle used by Thales was based on a recent linac installation at ALBA [3].

Radiation Considerations

In order to comply with radiation safety, an additional protection roof was installed to cover the traveling wave accelerator, the straight-branch beam diagnostics and dump. The total charge was also restricted for both modes during the commissioning phase.

The consequence of the radiation levels inside the bunker was underestimated. The linac electron gun high voltage device, EGUN HV, was found to be over sensitive to the hazardous environment. Purely linac operation generates a Gamma Dose Rate (GDR) of 0.05mSv/h at the gun cabinet, but with the addition of the nominal booster current 10mSv/h are measured. This GDR causes HV breakdowns destroying key electrical components on the EGUN driver board. Studies at ALBA [4] provided guidelines to the amount of radiation reduction required in the bunker, as the EGUN components are similar. An extensive radiation survey, together with Thales, was undertaken to reduce the GDR to 1mSv/h at the gun cabinet, allowing the SAT to be realised during nominal booster operation. Here, 5cm thick Lead walls were assembled at the main radiation source; the booster septum, in the gang way between the linac and booster to protect the 500MHz prebuncher and gun cabinet, and other shorter constructions enclosing individual booster magnetic elements, Fig. 3. The optic in the booster was also corrected using steerers to minimise radiation loss in the linac area.

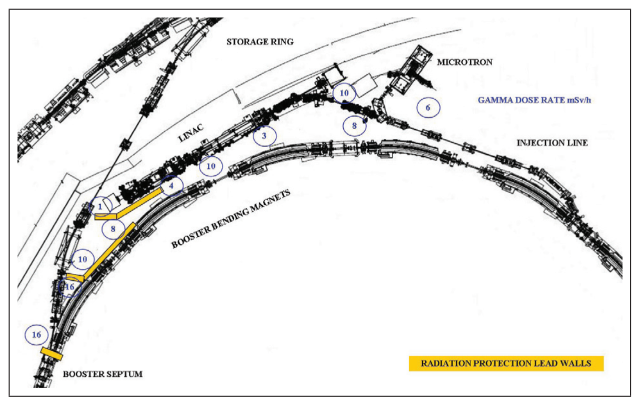

Figure 3: Radiation survey of bunker.

Emittance

In a region where the betatron size of the beam dominates, the transverse emittance can be measured by varying the strength of a single quadrupole. The transport matrix of an quadrupole - drift - monitor optic in the thin lens approximation, Eq. 1 was used to calculate the quadratic relationship between the up(0) and down(1) stream beam properties,

$$\sigma_1^2 = (1 + Lk)^2 \beta_0 - 2(1 + Lk)L\alpha_0 + L^2\gamma_0 \quad (1)$$

where σ is the rms beam size, L is the drift length, k is the scanning quadrupole strength, β,α and γ are the Twiss parameters. The monitor is down stream at position 1.

A fit of the beam size measured on the digital monitor is shown in Fig. 4. The numerical analysis of this fit indicates a LPM horizontal normalised emittance of 10π mm mrad.

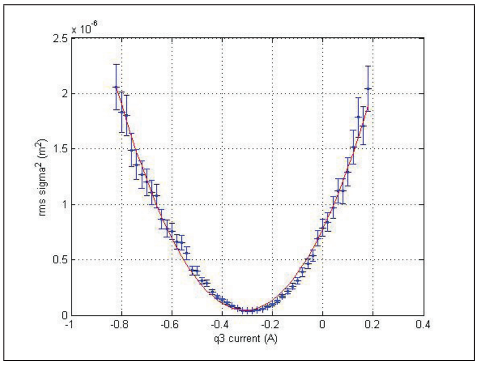

Figure 4: Typical LPM horizontal emittance measurement.

Energy Spread

The energy spread measurement was performed using the dispersion η in the bend branch. The online data from both branches was continually analysed using the correlation of the sigma matrix Eq. 1, and the transformation of the beta function through the bend, to find the energy spread Eq. 2.

$$\sigma^2 = \epsilon\beta + \eta^2(\delta E/E)^2 \qquad (2)$$

This dynamic principle of online measurement analysis was repeated rigorously to improve the linac phase settings that characterise the beam.

Transmission and Structure Temperature

The SAT provided the initial operating conditions for the linac. Since the acceptance, investigations towards optimal settings have been undertaken. The influence of the Glaser lens (GL) on the high charge SPM shown in Table 2, justifies, together with the series of sub and harmonic prebunchers their inclusion.

Table 2: SPM Charge Improvement due to Glaser Lens

I_{GL} (A)	0	10	20	30	45	50	55	75
Q_{bunch} (nC)	0.35	0.33	0.35	0.35	0.39	0.39	0.41	0.39

The Glaser lens has also been introduced to the LPM, to help improve the energy spread. Recent tests at the nominal booster injection energy 52.5MeV, show δE/E=0.2%rms. The traveling wave accelerator was also found to be at a sub-optimum working temperature. In comparison the temperature of the standing wave buncher can be well optimised by minimising the reflected power. However, to observe the slight miss-match in phase advance over 96 cells in the traveling wave structure, both the total energy gain and energy spread need to be monitored.

38°C was specified for the SAT but investigations using the cooling loop show the best result tend towards 34.5°C, Fig. 5. This can be expected for a wide-band structure when one assumes 50kHz per temperature degree inducing a 15° phase shift along the structure. The BESSY II master clock also needs to be taken into consideration here as it can change annually by ±10kHz.

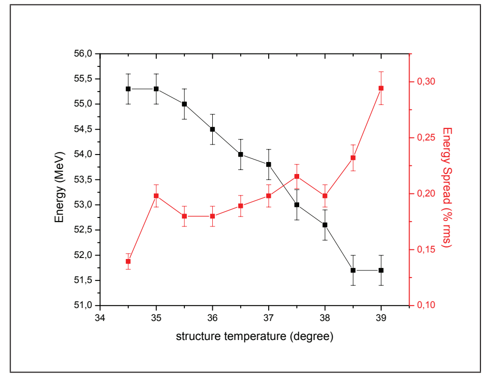

Figure 5: Optimising the accelerator structure.

Linac Injection into the Booster

The milestone of linac-booster injection was achieved on the 25th of July, two weeks before shut-down. In LPM, the transmission along the injection line mirrored that of the microtron, but the injection rate remained low. The general consensus is to keep the exact existing injection line optic, as the old magnets suffer badly from hysteresis, and adapt the linac section to suit. The changeover from local (Thales) to BESSY II master software remote control was also successfully tested.

CONCLUSION

The acceptance of linac operation at HZB has been approved. The linac was installed and commissioned within the annual summer shut-downs at the synchrotron facility. Minimal beam time was lost and all the desired beam parameters realised. Extensive radiation surveys have helped better understand this generation of turn key linacs. Online emittance and energy spread measurements provided a continual improvement in linac beam characteristics reaching an efficient operation level in both beam modes. Where prebunching cavities suppress emittance growth and RF phase adjustments minimise energy spread. The next stage is the full integration of the linac as a preinjector for the BESSY II storage ring.

Special thanks go to all the HZB machine group staff for the smooth integration of the linac.

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