THE INJECTOR FOR THE S-BAND TEST LINAC AT DESY

M. Schmitz
Deutsches Elektronen Synchrotron (DESY), Notkestraße 85, 22603 Hamburg, Germany
D. Yeremian
Stanford Linear Accelerator Center (SLAC), Stanford, CA 94309, USA

Abstract

The s-Band Test Facility currently under construction at DESY is expected to operate in a 2 μs multibunch mode with 50 Hz repetition rate. While having a constant average current of 300 mA within the macropulse, a variable interbunch spacing, which is required for wakefield studies, of 8 ns, 16 ns or 24 ns results in a maximum bunch charge of 7.2 nC. An injector which delivers such trains of bunches was designed and optimized by means of EGUN and PARMELA simulations. Since the testlinac and not the injector is the subject of investigation a conventional scheme based on reliable and well proven technology was chosen. Created by a pulsed thermionic gun, compression of the pulses is achieved by two subharmonic bunchers, running at 125 MHz and 500 MHz, as well as one β-matched travelling wave buncher running at the linac frequency.

1 INTRODUCTION

With the s-Band Test Linac at DESY it is intended to investigate the technical and financial feasibility of a s-Band Linear Collider project. The testlinac consists of 4 (β=1; 17 MV/m) travelling wave accelerating structures of 6 m length each. In between quadrupole tripletts serve for focussing. At the beginning of all this an injector has to deliver adequate bunches for the testlinac.

As mentioned in the abstract a flexible time structure is needed. Based on a 50 Hz repetition rate a 2 μs long bunchtrain with an average current of 300 mA is desired. Concerning the time structure within this bunchtrain 3 modes of operation are expected :

1.) 250 bunches with 8 ns bunch to bunch spacing and 2.4 nC/bunch $\Leftrightarrow$ 1.5 e^-/bunch

2.) 125 bunches with 16 ns bunch to bunch spacing and 4.8 nC/bunch $\Leftrightarrow$ 3.0 e^-/bunch

3.) 83 bunches with 24 ns bunch to bunch spacing and 7.2 nC/bunch $\Leftrightarrow$ 4.5 e^-/bunch

Mode **2.)** is proposed to be the one for a s-band collider.

The bunchlength at the exit of the injector is defined by the desired energy spread at the end of the linac. If used as an injector linac for the damping ring, with an energy acceptance of 1% (which is the parameter in the collider study), the corresponding bunchlenghth has to be $16^\circ_{3\text{GHz}} = 14.8$ ps.

The energy at the exit of the injector has to be high enough so that the beam is sufficiently relativistic. In that case the injector is fully responsible for the bunching and the first accelerating section takes over a bunch which longitudinal dynamics is already frozen. The clear-cut between bunching and acceleration guarantees an independant operation of the injector and accelerating sections. For this reason the beam should leave the injector with a kinetic energy of $E_{kin} \geq 3$ MeV $\Leftrightarrow \beta \geq 0.99$.

Requiring multibunch operation with high bunch charge and intensity stability, we decided for a thermionic gun with a gridded cathode followed by a bunching system using subharmonic and fundamental bunchers. The design of the gun and the bunching system is discussed in the following sections.

2 GUN DESIGN

The current the gun has to deliver is defined by the length of the gunpulse and its charge. In order to be captured by the first subharmonic buncher (SHB) the gunpulse should have a length in the order of 90° of its frequency. In order to relax the requirements on the gun this frequency has to be as low as possible but nevertheless has to match with the time structure of the bunchtrain. That's why in our case the first SHB has to work at 125 MHz, which implies the gunpulse to

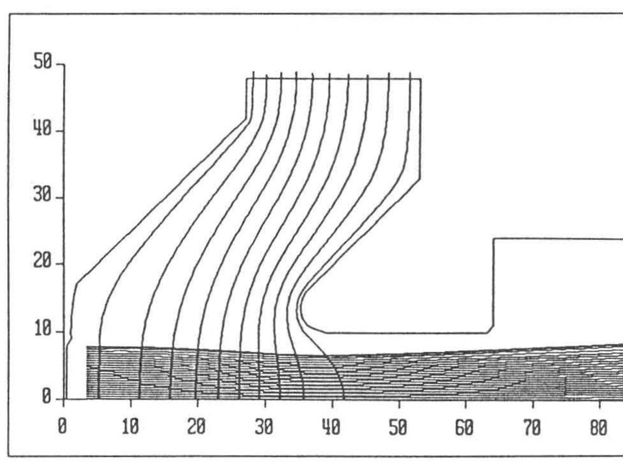

Figure 1: *Gun geometry r [mm] vs z [mm] with equipotential lines and space charge limited electron rays calculated for an anode voltage of* 90 kV

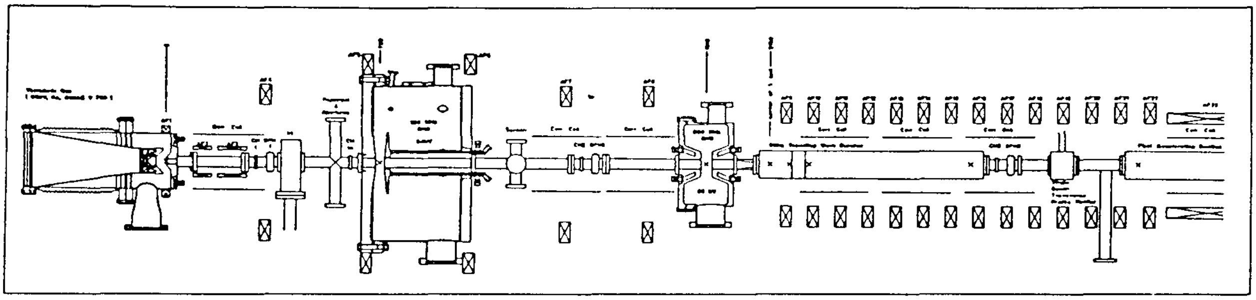

Figure 2: *Overview of the injector for the DESY s-band test facility*

have a length in the order of about FWHM≈ 2 ns. Including a safety margin of 60 % the maximum charge in this pulse has to be 12 nC = $7.5 \cdot 10^{10} e^-$ for the 24 ns interbunch spacing. Thus the gun has to be capable of delivering up to about 6 A of current.

The gunvoltage of 90 kV has been chosen as low as possible in order to simplify bunching. On the other hand this value is high enough so that debunching space charge effects in the 75 cm long driftspace between the gun and the first SHB are tolerable.

To be pulsed the gun needs a grid electrode near the cathode. Based on the EIMAC Y 796 cathode-grid assembly, which emits from a circular cathode area of 2 cm^2 equivalent to 8 mm in radius, a gun geometry was modelled by means of the computer code EGUN. The result is shown in figure 1. With a 34 mm wide anode cathode gap this gun has a perveance of 0.22 $\mu A/V^{1.5}$, i.e. it delivers a 6 A space charge limited current at 90 kV. At this voltage a maximum electrical fieldstrength of 81 kV/cm appears at the surface of the anode "nose". The normalized and absolut 100 % emittances at the gun exit are $\epsilon_n^{100\%} = 9.3\,\pi \cdot \text{mm} \cdot \text{mrad}$ resp. $\epsilon_{abs}^{100\%} = 15.0\,\pi \cdot \text{mm} \cdot \text{mrad}$. Together with the beam radius at the waist ($\alpha_{x,y} = 0$) a beta value of $\beta_{x,y} = 2.97$ m can be calculated. These parameters were used to characterize the transverse beam properties at the start of the PARMELA simulation.

The gun is manufactured in the university of Aachen and is almost completed. A 250 mm long ceramic is used as an isolator. The cathode is carried by a conical metallic tube that runs through the ceramic and is flanged on to the high voltage end of the isolator.

Pulsing the cathode will be done by means of a fast high power (≈ 1 kW) gunpulser using switch tube technology. To be as near as possible to the cathode this pulser is housed inside the conical tube right behind the cathode. Together with this pulser the gun is expected to deliver FWHM ≤ 2.5 ns (FW ≤ 3.5 ns) pulses with a peak current of 6 A [1]. By suitable triggering the desired time structure of the bunchtrain is produced right at the gun. The bunchcharge is controlled by the amplitude of the gunpulser and the cathode-grid bias voltage.

3 BUNCHING SYSTEM

Starting with the EGUN calculated transverse beam parameters at the the gun exit (see section 2) a 90 kV/12 nC pulse with a length of FWHM=2.5 ns (FW=3.0 ns) was used as an input to the PARMELA code in order to optimize the process of bunching. The result of the injector is sketched in figure 2.

The 30 mm wide gap of the 125 MHz reentrant type SHB is centered at $z = 75$ cm. The previous driftspace is used up for beam instrumentation to measure the position (BPM), the current (CM) and the emittance (pepperpot) of the beam. Additionally a valve and the matching solenoids require some space there. For optimum bunching the gap voltage of the first SHB has to be 34 kV. In that case more than 80 % of the gunpulse is bunched into 120° of 500 MHz at $z = 191$ cm. That's why the 40 mm gap of a 500 MHz SHB is centered there. The drift of 116 cm between the gaps of both SHB's accomodates the fluorescent screen for the pepperpot as well as a BPM and a CM.

The best choice for the 500 MHz SHB amplitude is 36 kV. Since the beam was still modulated at the entrance to the 500 MHz SHB the optimum longitudinal focal point appears already 24 cm behind the 500 MHz gapcenter at $z = 215$ cm. At this position the bunch has a length of FWHM=0.19 ns equivalent to ≈ 200° of s-band, in which more than 80 % of the initial charge can be found.

The fouriercoefficients of the MAFIA calculated electrical field distribution along the cavity axis was used to model the SHB fields in PARMELA. Their radial dependance is calculated in PARMELA based on the general solution of a cylindersymmetric problem, i.e. independant of the actual boundary conditions given by the cavity geometry. Both cavities are made from stainless steel and fabricated at the university of Aachen. The MAFIA calculated normalized shunt impedance is $R/Q = 82\,\Omega$ for the 125 MHz cavity and $R/Q = 101\,\Omega$ for the 500 MHz cavity. The unloaded quality factor for both cavities is $Q_0 \approx 2650$. The cavities will be driven by 10 kW pulsed transmitters. Assuming a loaded $Q_l \approx 1200$, which indeed has been measured at the 125 MHz cavity that is already completed, a maximum gap voltage of 44 kV in the 125 MHz cavity and 49 kV in the 500 MHz cavity can be built up.

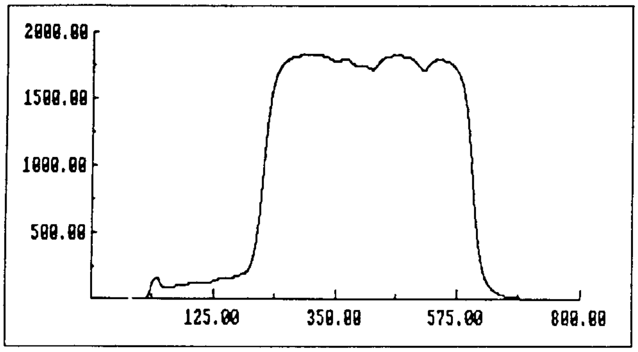

Figure 3: *Solenoidal fieldstrength B_z [Gauss] vs longitudinal position z [cm] along the injector*

Approximately a factor of 13 in compression is achieved up to this point with both SHB's. Still too long for the linac a 3 GHz β-matched travelling wave structure (starting with the first cellcenter at $z = 215$ cm) compresses the bunch by another factor of 20 down to FWHM=$10^\circ_{3\text{GHz}} = 9.3$ ps and simultaneously accelerates it up to about 4 MeV. About 90 % of the initial charge is bunched into 15° of s-band corresponding to an energy spread at high energy of ± 0.43 %. For the simulations presented here this travelling wave buncher (TWB) still consists of two separate structures, i.e. a 4 cell $\beta = 0.6$, 6.7 MV/m structure followed by a 19 cell $\beta = 0.95$, 14 MV/m structure with a driftspace of 9.2 cm between the last cell of the first structure and the first cell of the second structure. PARMELA simulations aiming to have only one TWB structure with tapered cellength are not finished yet.

Before entering the first $\beta = 1$, 17 MV/m accelerating section a drift of about 60 cm allows for installation of CM, BPM and a fast optical transition radiation monitor to measure the transverse pofile of single bunches by means of a short gated camera.

4 TRANSVERSE DYNAMICS

Up to the 500 MHz SHB the beampipe has an inner diameter of 34 mm. Transverse focussing of the beam is done by a solenoidal field B_z, which strength as a function of the position z in the injector is shown in figure 3. At the guncathode the field is set to zero by means of a bucking coil. With two matching solenoids the beamsize is adjusted to fill about 70 % of the beampipe, since a large ratio reduces the space charge effects. This beamsize is tried to be kept constant up to the 500 MHz SHB.

Just before entering the 3 GHz TWB the beam is focused down to half the transverse size by means of a steep rise of the magnetic field, which finally reaches its maximum at 1800 Gauss. This fieldstrength is kept constant up to the middle of the first accelerating section.

The normalized horizontal rms-emittance $\epsilon^{rms}_{n,x}$ as a function of the position z along the injector is plotted in figure 4. Starting with $1.8\,\pi \cdot$ mm $\cdot$ mrad at the gun exit the rms-emittance at the exit of the injector has increased by a factor of about 50 due to a strong emittance growth in the first few cells of the 3 GHz TWB. In travelling wave structures also defocusing fields exist, which of course vary sinusoidally in time with the frequency of this structure. As a consequence the defocusing forces are different for each longitudinal segment of the bunch. This effect is more severe the longer the bunch is compared to the period of the rf-field. That's why the emittance growth happens in the 3 GHz TWB. When the bunch is short all particles are more or less affected in the same manner and the emittance stays almost constant at around $90\,\pi \cdot$ mm $\cdot$ mrad.

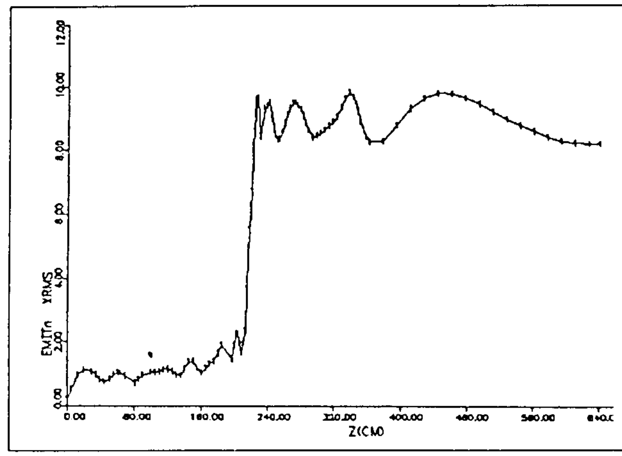

Figure 4: *Normalized horizontal rms-emittance $\epsilon^{rms}_{n,x}$ [$\pi \cdot$cm$\cdot$ mrad] vs longitudinal position z [cm] along the injector*

5 SUMMARY

The design of the injector for the DESY s-band test facility is based on a conservative scheme using a thermionic high intensity pulsed gun, two subharmonic bunchercavities and a travelling wave buncher which is still under simulation studies. The expected performance as simulated with PARMELA was presented. At the exit of the injector roughly 90 % of 12 nC initial charge is bunched into 15° of s-band. The overall factor in compression is more than 200. The transverse emittance growth is significant but it saturates at a normalized rms value of around $90\,\pi \cdot$ mm $\cdot$ mrad. The bunch leaves the injector sufficiently relativistic with an energy of about 4 MeV.

6 REFERENCES

[1] Specification of gunpulser, HERMOSA Electronics, February 1994