THE INJECTOR LINAC OF THE DELTA-FACILITY

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Abstract

The DELTA-(**D**ortmund **El**ectron **T**est **A**ccelerator)-facility is a 1.5 GeV synchrotron radiation light source consisting of a storage ring, a full energy booster synchrotron and an S-band linac (2998.55 MHz) of 65-100 MeV output energy. In its major components the linac has been constructed out of parts of the old 400 MeV linac of the University of Mainz. Two of the old high gradient sections have been combined with a 50 keV gun (2 A, 2-20 ns, 100 Hz) and a 4 MeV buncher section. First operation started end of 1994. The linac is now operating routinely as injector for the booster and delivers 300 mA at 70 MeV. The paper presents the layout and present data of the linac, the rf- and monitoring system and summarises the operation experience and plans for future upgrade.

1 INTRODUCTION

The DELTA-facility at the university of Dortmund [1,2] presently under commissioning is a 3rd generation synchrotron radiation light source of 1.5 GeV maximum energy. The storage ring Delta is fed by the full energy booster synchrotron Bodo (Booster Dortmund) operating as a ramped storage ring with a maximum repetition rate of 0.2 Hz. Due to the rather low injection rate and to the fact that single bunch operation in the booster is necessary for driving an FEL [3] in the storage ring two major possibilities for an electron injector had been discussed in the beginning:

- a commercial microtron of 20-50 MeV delivering a few mA at 20-50 MeV combined with a harmonic number h = 1 or 2 buncher cavity for the booster
- a linear accelerator with a modest output energy of roughly 100 MeV and a beam current of appr. 1 A

In 1989 the 400 MeV electron linac at the university of Mainz was finally shut down and the decision has been made to use major parts of the old components offered by the Mainz authorities to reconstruct a 100 MeV linac fulfilling the above requirements.

2 LAYOUT AND SET UP OF THE DELTA LINAC

2.1 General Performance

Using two of the old Mainz $\beta = 1$ S-band accelerator sections powered with 20 MW each the linac is able to produce a 100 MeV output beam. For longitudinal pulse compression a 3.8 MeV buncher section (LAL, Orsay, LIL-type [4]) is installed at the front end together with a 50 keV electron gun with incorporated prebuncher. For single bunch operation in the booster a 2 ns (500 MHz cavity) beam pulse is required. The main design values are listed in Table 1 (see also Figure 1).

operating frequency	2998.55 MHz
electron gun	50 kV, 2 A, 2 ns, 1-100 Hz
longitudinal pulse compression	prebuncher and 3.8 MeV buncher
accelerator sections	2 β=1 constant gradient sections; length 4.2 m each
output beam energy	100 MeV
output current	1 A, 2 ns, 1-100 Hz
$\Delta E/E$	+/- 2%
abs. output emittance	$\varepsilon < 1\ \pi$ mm mrad (100%)

Table 1: General design performance of the linac

2.2 Electron Gun

A new triode electron gun with 50 kV extraction voltage has been developed [5] based on the old Mainz gun-body. Based on the EIMAC Y796 cathode with 16.4 mm diameter the extraction optics is designed to produce a beam waist directly in front of the single cell prebuncher cavity located 65 mm downstream the cathode. EGUN calculations result in an rms-emittance of $\varepsilon = 16\ \pi$ mm mrad at 2.6 A.

2.3 Prebuncher and Buncher

The single cell reentrant cavity incorporated in the gun-body is followed by a short on-axis coupled $2\pi/3$-mode standing wave buncher section (LAL, Orsay) with graded-β-profile (β = 0.92,0.98,1.0) consisting of 6 cells plus 2 end-cells (see Figure 1). It is equivalent to the buncher operating at the LIL-injector at CERN [6]. The nominal gradient is calculated to 16 MV/m at 1.7 MW rf-power giving an increase in energy of 3.8 MeV for the reference particle.

2.4 Accelerator Sections

To increase the energy from 3.8 MeV to the nominal output energy of 100 MeV we installed two of the old Mainz accelerator sections. They are of the $2\pi/3$ - mode

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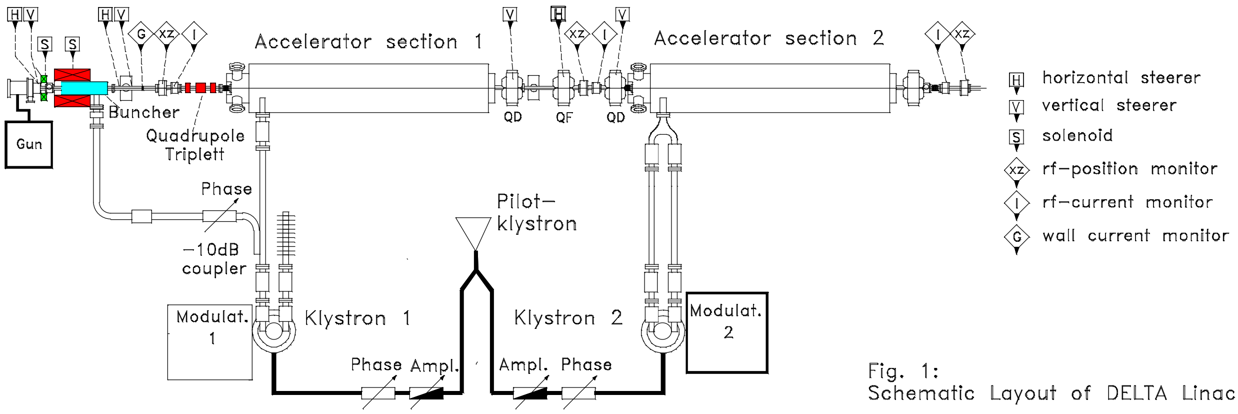

Fig. 1:
Schematic Layout of DELTA Linac

travelling wave type consisting out of 124 cells with integrated waveguide rf-dump. From calculations based on the geometrical dimensions we obtained a filling time of 0.7 µs (in good agreement with the performed measurements) and a shuntimpedance of 42 MΩ/m. Each structure is fed by a 20 MW klystron at 4.5 µsec pulse length with a repetition rate of max. 100 Hz.

2.5 RF-System and RF-Network

The RF-system and the corresponding network is shown in Figure 1. It consists mainly of two modulators and two old Thomson F2042E klystrons with 20 MW output power. The modulators and the PFN-networks have been rebuilt out of the old parts from Mainz in a more compact way and produce a 270 kV, 240 A pulse with a pulse length of 4.5 µs with a maximum rep. rate of 100 Hz. To feed the high energy accelerator section the two rf output waveguides of the klystron are combined under vaccum and need a careful adjustment of the rf phase via waveguides with adjustable cross-section. Between the rf-windows we use 2 bar abs. SF_6. For the low energy part of the accelerator it was foreseen to combine the two output waveguides with a combiner under SF_6 to ensure a sufficient supply of rf power for the buncher via a 10 dB coupler followed by a phase shifter. The first power tests showed rather quickly that this way of operation is not possible with the old E-type combiner. To ensure operation for the commissioning of DELTA we decided to use one rf waveguide only with reduced available rf-power for the buncher and the first section (Figure 1, section 3.2).

2.6 Monitoring and Linac Control

Three TM_{010}-mode cavities with circular cross-section operating at the linac frequency are installed. High coupling of the output antennas and low Q-values give very sensitive and reliable information for 2 ns beam pulses and the achieved pulse compression. The beam position is obtained with three installed cavities with quadratic cross-section operating in a mixed TM_{210}- and TM_{120}-mode.

For transmission measurements we use two wall current monitors downstream the buncher and at the end of the linac, where also a fast 50 Ω-Faraday-Cup is mounted.

Horizontal and vertical steerers are available at the indicated positions in Figure 1.

2.7 Transverse Optics

The control of the horizontal and vertical beam dimensions is a crucial point at the front end of a high intensity linac. An injection energy of 50 keV and a beam current of 2 A together with the high acceleration gradient (16 MV/m) of the buncher give rise to strong defocusing forces. Since the prebuncher is part of the gun-body and should be located close to the buncher no space was available to install a large-scale low energy solenoid transport line as it has been done at the LIL-Injector at CERN [4,6]. Due to the available space we installed two solenoids (built in house) of different size and magnetic strength (see Figure 1). Solenoid 1 is located 5.5 cm downstream the prebuncher (L_{eff}= 5.5 cm, B_{max}= 300 G), solenoid 2 located above the buncher section (L_{eff}=40 cm, B_{max}= 2200 G). A small size quadrupole triplett is mounted in front of the first accelerator section to match the beam emittance to the acceptance of the downstream linac part. We are not using the built-in solenoids above the accelerator sections but installed a further triplett between the sections and one more quadrupole at the end of the linac as first part of the transfer-line to the booster [2].

The transverse beam dimensions have been calculated with the program ENVEL [7], which solves the envelope equation taking into account emittance, space charge and focusing forces as well as the defocusing forces generated by the prebuncher and buncher rf. Figure 2 shows that the beam is well confined especially inside the buncher.

2.8 Longitudinal Pulse Compression

To achieve an energy spread of ΔE/E = +/- 2% for a substantial fraction of the beam the phase spread at the entrance of the accelerator section has to be limited to

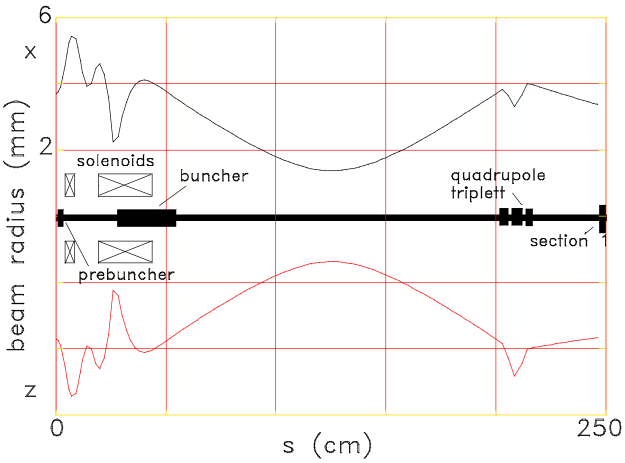

Fig. 2: Transverse enveloppe in the low energy part of the linac

23^0. Calculations carried out with the multiparticle code PARMELA showed quite similar results compared to the calculations at CERN [4]. The best bunching efficiency is obtained at 16 MV/m accelerating gradient of the buncher which corresponds to an energy increase of 3.8 MeV. Due to the quite large distance of 24 cm between prebuncher and buncher the theoretical value for the bunching efficiency was calculated to $I_{out}(23^0)/I_{in}(360^0)$ = 40% at 2 A gun current. We saw only a negligable influence arising from the fact that the input energy is only 50 keV instead of 80 keV in the case of LIL. The bunching efficieny is strongly related to the accelerating gradient of the buncher and decreases drastically with reduced rf-power (see section 3).

3 LINAC OPERATION

3.1 First Operational Results

After a 2 years period of construction the first beam was launched in October 1994 and after 2 days accelerated to 60 MeV and two weeks later to 75 MeV. The poor overall beam transmission of 2-3% at that time was caused by the lack of transverse focusing and in addition arised due to timing problems from the combination of a travelling wave and a standing wave resonator with different filling times fed by the same klystron (short rf-pulse length of 3.5 µs). From March until summer 1995 the linac was operating routinely for the beam injection into the booster Bodo.

3.2 Status of the Linac

Short after the installation of the large scale solenoid above the buncher and modifications concerning the PFN-network (4.5 µs rf pulse length) and a careful cleaning and rf-conditioning of the buncher (electron multipactoring during operation in summer) the beam was accelerated to 78.1 MeV in October 1995 with an overall beam transmission of 20% with a large energy spread $\Delta E/E$ > +/-10% caused by the low available rf-power of < 1 MW instead of 1.7 MW necessary for the design operation of the buncher (see Figure 1 and section 2.5). Routine operation was achieved since end of 1995 for the commissioning of Bodo and Delta. Table 2 summarizes the actual beam data.

extracted gun current	1.5 A
beam pulse structure	2 - 20 ns
output beam energy	60 - 78 MeV
output energy for Bodo	68 MeV
output beam current	300 mA, 20% transmission
output beam current	90 mA, $\Delta E/E$ = +/- 2%
abs. output emittance	$\varepsilon < 1\ \pi$ mm mrad (100%)

Table 2: Status of linac beam performance

3.3 Future Upgrade

During the summer 1996 shutdown the first F2042E klystron will be replaced by the more or less compatible TH2100 klystron equipped with only one rf output waveguide. An rf power of more than 20 MW is then available for section 1 and the design buncher operation at 1.7 MW can be easily obtained resulting in a better transmission at a reduced energy spread and increased output energy. In a later stage also the second klystron will be replaced by the new type. An available output energy of more than 100 MeV will naturally facilitate the injection into the booster since magnetic remanence effects are drastically reduced [1].

To increase the bunching efficiency a shorter distance between prebuncher and buncher is required resulting also in major alterations concerning the transverse focusing system.

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