PRESENT AND FUTURE PERFORMANCE OF THE DELTA INJECTOR LINAC

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Abstract

After a two years period of construction the routine operation of the 100 MeV electron linear injector started in summer 1995. The linac serves as injector for the 1.5 GeV DELTA- (Dortmund Electron Test Accelerator)- synchrotron radiation facility. In its major parts the linac has been constructed out of parts of the old Mainz 400 MeV linac (final shut down in 1989). The linac consists of a new developed 50ÊkeV gun and a 4 MeV buncher for longitudinal pulse compression and two travelling wave structures. In the present state of operation the linac delivers a 70 MeV, 300 mA beam within 2-20 nsec at 10-100 Hz.

The paper covers design and performance of the linac and its components including monitoring, transverse and longitudinal optics together with experimental results and the expected performance of the linac after modifications concerning the rf-transmitters and part of the rf-network.

Introduction

The DELTA-facility at the university of Dortmund [1,2] is a 3rd generation 1.5 GeV synchrotron radiation light source. 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. This rather low injection rate and the necessity to run the booster in single bunch operation in order to drive an FEL [3] in the Delta ring imply short beam pulses at high currents to be delivered from the injector.

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 (accelerators as well as the modulators and the rf-network and klystrons) offered by the Mainz authorities to reconstruct a 100 MeV linac fulfilling the above requirements.

Setup and Layout of the DELTA Linac

General Performance

Two of the old Mainz ß = 1 S-band accelerator sections powered with 20 MW each produce a 100 MeV output beam. To ensure operation at high currents in the ampere range the front end had to be totally rebuilt. 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. The main design values are listed in Table 1. The schematic layout is shown in 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
output beam energy	100 MeV
output current	1A, 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

Low Energy Part of the Linac

Set up. A 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 the extraction optics produces a beam waist directly in front of the prebuncher cavity (65 mm downstream the cathode). EGUN calculations result in an rms-emittance of $\varepsilon = 16\ \pi$ mm mrad at 2.6 A.

The single cell reentrant cavity incorporated in the gun-body is followed by a short buncher section manufactured by LAL, Orsay (see Table 2). It is equivalent to the buncher operating at the LIL-injector at CERN [6].

length	0.45 m
resonator type	on-axis-coupled, $2\pi/3$-mode standing wave
shuntimpedance, Q	23 MΩ/m, 13600
ß-profile	ß = 0.92, 0.98, 1.00
number of cells	6 plus 2 endcells
energy gain (ref. particle)	3.8 MeV (1.7 MW)
accelerating gradient	16 MV/m (1.7 MW)

Table 2: Performance of S-band buncher section.

Transverse Optics. The injection energy of 50 keV and a beam current of 2 A together with the high accelerating 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 (Leff= 5.5 cm, Bmax= 300 G and Leff= 40 cm, Bmax= 2200 G, see Figure 1 and 2). 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. The transverse beam dimensions have been calculated with the program ENVEL [7], which solves

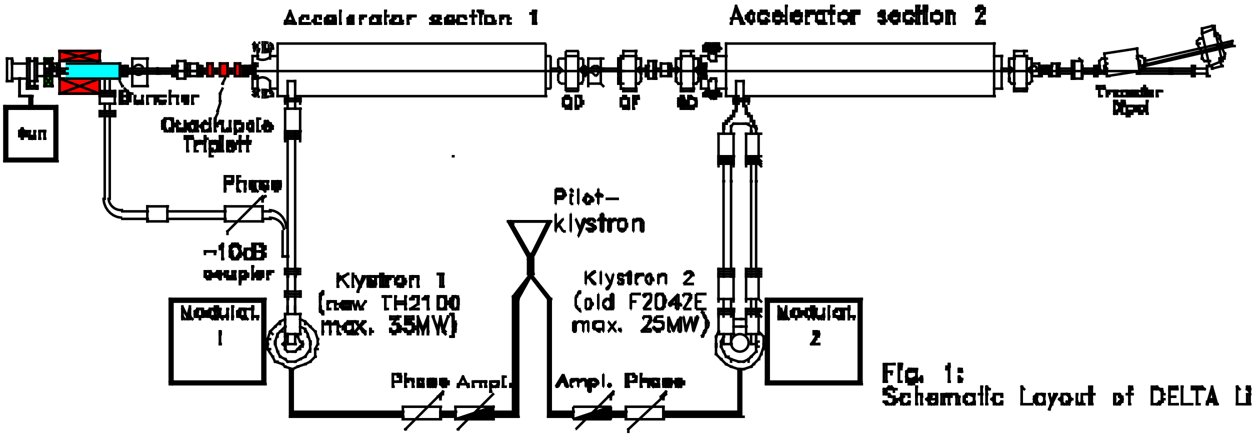

Fig. 1: Schematic Layout of DELTA Linac

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 under nominal operating conditions.

Longitudinal Pulse Compression. An output energy spread of ΔE/E = +/- 2% for a substantial fraction of the beam can be obtained if the phase spread at the entrance of the main accelerator sections is limited to 23^0. PARMELA-calculations showed quite similar results compared to the calculations at CERN [4]. Even for an input energy of 50 keV, 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. The bunching efficieny is strongly related to the accelerating gradient of the buncher and decreases drastically with reduced rf-power (see below).

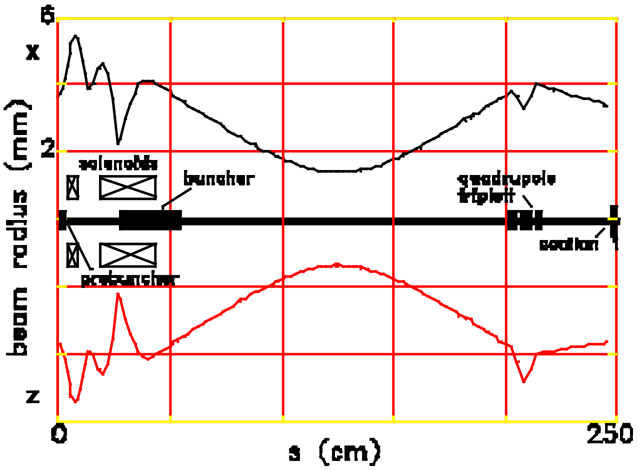

Fig. 2: Transverse enveloppe in the low energy part of the linac

High Energy Part of the Linac

Accelerator Sections. We installed two of the old Mainz accelerator sections (CGR-MeV) to increase the energy from 3.8 MeV to the nominal output energy of 100 MeV. These sections are of the 2π/3-mode travelling wave type and had been installed in Mainz for replacement of the older π/2-type structures and for upgrading the linac. Unfortunately no information was available about these structures. From theoretical considerations and from direct measurements we obtained the data given in Table 3.

length of section	4.2 m
field mode	2π/3, travelling wave
group velocity v/c	0.011 - 0.036
filling time	0.7 μsec
Q	10,000
shuntimpedance	42 MΩ/m
iris aperture diameter	30 - 20 mm
attenuation	0.62 Np
max. RF-power	20 MW at 4.5 μsec.

Table 3: Performance of the accelerator sections

Transverse Optics. We are not using the built-in solenoids above the accelerator sections but installed a 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].

RF-System and RF-Network

The RF-system and the corresponding network is shown in Figure 1 (status end of this year). It consists mainly of two modulators and two 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 old F2042E 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 we still have an old F2042E klystron operating [8], where we use only one output waveguide to ensure operation for the beam injection into the DELTA rings. This old klystron will be replaced during the autumn shut down by the new TH2100 type providing more than 20 MW with one rf-output flange.

Beam Monitoring

Three TM010-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 TM210- and TM120-mode.

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

Present Status of the Linac

The first beam was launched in October 1994 (60 MeV) and two weeks later accelerated to 75 MeV. From March until summer 1995 the linac was operating for the beam injection into the booster Bodo with an overall transmission of only a few percent.

After changes concerning the transverse focusing in the low energy part [8] and a careful cleaning 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 still rather large energy spread of $\Delta E/E > +/-10\%$ caused by the low available rf-power of < 1 MW instead of 1.7 MW necessary for the design operation of the buncher (see above). Routine operation was achieved since end of 1995 for the commissioning of Bodo and Delta. Table 4 summarizes the actual beam data.

extracted gun current	1.5 A
beam pulse structure	2 - 20 nsec
output beam energy	60 - 78 MeV
output energy for Bodo	68 MeV
output beam current	300 mA, 20% transmission 90 mA, $\Delta E/E = +/- 2\%$
abs. output emittance	$\varepsilon < 0.8\ \pi$ mm mrad (100%)

Table 4: Status of the present linac performance

At the present time the injector of the DELTA facility offers a 90 mA beam at 68 MeV within an energy spread of +/- 2% at variable pulse lengths of 2 - 20 nsec. This results in a 300 μA - 3 mA average beam current accelerated in the booster and an increase of stored beam current in the storage ring of 100 μA - 1 mA every 5 - 6 sec.

Future Upgrade

To speed up the filling time for the storage ring, the first F2042E klystron will be replaced during the autumn shut down 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 according to the specification (Table 1). In a later stage (summer 1997) 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].

Due to the high current levels the distance between prebuncher and buncher has to be decreased. This will result in a better bunching efficiency but will require more effort concerning transverse focusing.

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