The TESLA Test Facility (TTF) - A Description of the Superconducting 500 MeV Linac

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Abstract

The energy range in e^+e^- collisions beyond LEP can only be explored by the use of linear colliders. Aiming for 500 GeV center of mass and luminosities in excess of $10^{33}cm^{-2}s^{-1}$, TESLA proposes to use superconducting (s.c.) standing wave RF structures at a gradient of 25 MV/m ($Q_0 = 5 \times 10^9$) and a frequency of 1.3 GHz. A total of 800 bunches each spaced 1 μs apart are accelerated. In order to establish a technical basis for such a s.c. linear collider the TTF is an essential part of the development of injectors, accelerating cavities, cryostats and new beam diagnostic techniques. The test of a string of 32 cavities with beam at an accelerating gradient of 15 MV/m and for different time structures of the injected beam is planned in an installation at DESY, Hamburg. Beam optics, alignment and high order mode (HOM) excitation have to be studied. The installation is described and the contributions of the different collaborators to the facility are reported.

1 INTRODUCTION

Worldwide, there are a number of groups pursuing different linear collider design efforts. The TESLA activity [1] is one of these R&D effords, differing from the others in its choice both of superconducting accelerating structures and of low frequency (L-band, 1.3 GHz; see also [2]). As one of these R&D groups, TESLA plans to have a working prototype test facility in the 1997 time scale which supports the development of a s.c. collider.

The TTF is to be located at DESY, with major components flowing in from the members of the TESLA collaboration. Although it is of highest priority to prove the feasibility of reliably achieving accelerating gradients of 15 MV/m or more, the TTF has also to show that the cavities can be assembled into a linac test string successfully operated with auxiliary systems to accelerate an electron beam to 500 MeV. Furthermore, different experiments to be carried out on the TTF linac have been defined and partly outlined in detail now so that the necessary diagnostics can be set up. This covers not only the more typical beam experiments but also the cryogenics and RF measurements that are needed in order to confirm the idea of a superconducting linear collider.

2 THE TTF LINAC PROGRAM

Although a full comparison of the TTF linac's parameter with a potential TESLA 500 linear collider [3] can not be carried out here, Tab. 1 lists the most important items.

Table 1: TESLA 500 - TTF linac parameter comparison.

Parameter	TESLA 500	TTF linac
Linac Energy	250 GeV	500 MeV
Accelerating Gradient	25 MV/m	15 MV/m
Quality Factor Q_0	5×10^9	3×10^9
No. of Cryo Modules	many	4
Single Bunch $\Delta E/E$	1.5×10^{-3}	$\approx 10^{-3}$
Bunch to Bunch $\Delta E/E$	10^{-3}	$\approx 5 \times 10^{-3}$
Beam Current	8 mA	8 mA
Macro Pulse Length	0.8 ms	0.8 ms
Injection Energy	10 GeV	10-15 MeV
Lattice β	66 m	12 m
Bunch Rep.Frequency	1 MHz	216 / 1 MHz
Bunch Population	5×10^{10}	$0.023/5 \times 10^{10}$
Bunch Length, rms	1 mm	1 mm
Emittances $\gamma\sigma^2/\beta$	20, 1 μm	3μm
Beam Size, Injection	60, 20 μm	1 mm
Beam Size, End of Linac	50, 12 μm	0.35 mm

The time structure of the beam, i.e. bunch frequency, bunch separation, and bunch length as well as the number of particles per bunch depends clearly on the injector. In a first step a design was chosen which is intended to be relatively straight forward (see Sect. 3). Both, the emittances and the the beam sizes are determined of the injection system intended for TESLA 500 (a 10 GeV system is foreseen) and therefore cannot be met by the TTF linac. Nevertheless, there are a number of respects in which TESLA 500 and the TTF linac are sufficiently similar, so that the TTF linac experience will feed directly into the TESLA 500 design. Some aspects of the full scale linear collider can be checked at the TTF linac, others may be difficult or even impossible to check. This fact is reflected by the following list.

<u>What the TTF linac does check:</u>

- Gradient achievable [4]
- Cavity construction and processing techniques [5]
- Input and HOM coupler designs [5]
- RF control of multi-cavity systems [5]
- Lorentz force detuning effects and control [6]
- High peak power processing [7]

- Vacuum failure recovery potential
- cryostat design [5]
- Cryogenic operation
- Dark current [8]
- Energy and position feedback
- Alignment and its stability [8]
- BPM systems [9]
- First iteration on projected system costs

What may be difficult to check:

- Q_0 and HOM measurements are not easy
- Wake field measurements only far of axis
- Cavity alignment via wake fields hard (polarization)
- TESLA 500 bunch charge hard to achieve in time scale of TTF linac
- Accurate cost projection to mass production

What the TTF linac does not check:

- Emittance growth
- Vibration sensitivity
- Many features of an overall TESLA 500 facility

3 THE TTF LINAC

The TTF Linac, as it is shown in Fig. 1, consists of a 250 keV room temperature injection, a short superconducting linac followed by a 15 MeV beam analysis area and an optics matching system, the linac itself consisting of four cryomodules with eight cavities each, and the 500 MeV beam analysis area.

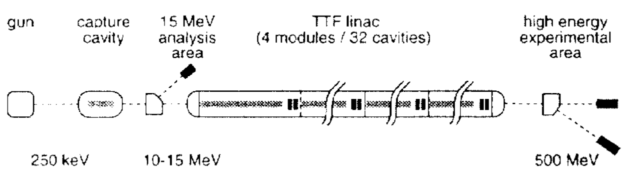

Figure 1: Schematic layout of the TTF linac. The overall length of the installation at DESY [10] amounts to ≈85 m; the drawing is not to scale.

3.1 Injector

Two injectors are planned for the TTF linac. The first, injector I, is intended to be relatively straight forward in design to provide the TESLA design current, but not the large bunch spacing of 1 μs and rather intense bunches (5 $\times 10^{10}$ electrons). In its initial form, injector I [11] will operate with the parameters as shown in Tab. 1, first column TTF linac. A later variant may operate at another subharmonic of the linac frequency and will provide higher charge per bunch. The second, injector II, is intended to provide the TESLA 500 bunch spacing and intensity. Here a design based on a laser driven photo cathode is considered and first designs are on the way. Nevertheless, neither of the two injectors will have the transverse emittance ratio of TESLA 500.

The warm part of injector I starts with a grid controlled thermionic gun as the source. The anode voltage of 40 kV accelerates the produced bunches ($2.3 \cdot 10^8 e^-$ in 50 deg at 216.7 MHz) to an electron velocity of $\beta = 0.37$ with which the beam is injected into a 1 m long electrostatic preacceleration tube. Bunch compression is performed by means of a 6^{th} subharmonic buncher cavity (SHB) which is operated in the accelerating π-mode and causes a change in velocity along the injected bunch length. The converging bunch is then transported through the beam line down to the entrance of a superconducting 15 MeV injector linac which contains one standard 1 m long nine-cell TESLA cavity.

This accelerating structure has a crucial influence on the beam quality at the end of the injector. As a standing wave, $\beta = 1$ cavity it has three major impacts on the beam optics. At first, the large leakage field, which the injected electrons see in the beam tube in front of the first cell, acts as a decelerating field. Second, the low velocity of the 250 keV ($\beta = 0.74$) electrons results in a phase slippage in the first cell. The consequence is an energy modulation but fortunately also a further bunch compression. And third, the field of a standing wave cavity has a strong focusing influence on the transverse dimensions of the electron beam [12]. Although a rough estimate of some of the effects can be made analytically, a complete simulation has been carried out using the tracking code PARMELA. This calculation also takes the space charge effects into account.

The accelerated electron beam can be studied in the low energy beam analysis area behind the injection linac. Transverse and longitudinal phase space volume and orientation will be measured. Therefore several diagnostic stations are used together with a focusing quadrupole triplet. The influence of the accelerating gradient and its focusing effect in the transverse phase space will be seen. The energy stability within the 800 μs macro pulse has also to be detected.

3.2 Linac Beam Optics

The already above mentioned first quadrupole triplet will be used together with a second triplet to allow the matching of the beam to the optics lattice used along the linac. Although this matching strongly depends on the orientation of the injector beam in the transverse phase space, the chosen system is proper to handle injector output energies from 10 to 15 MeV.

The lattice along the TTF linac consists of four cells, each having a superconducting quadrupole doublet and a beam position monitor at the end of a string of 8 s.c. cavities. For beam optics calculation one cell is basically represented by a focusing element 'F', a short intermagnet drift 'I', a defocusing element 'D' and finally a long drift 'O'. The matching to this FIDO lattice is strongly disturbed by the already mentioned rf-focusing which has to be taken into account at least for the first main linac cavities. Nevertheless, detailed beam optic calculations achieved a perfect matching with a β-function equal to the cell length of $\approx$12 m (module length).

Starting with this β-function, the accelerated electron beam (now 500 MeV) has to be transported through the high energy beam analysis area down to the end of the beam line, to the beam dump. It is planned to use one more quadrupole doublet together with the last superconducting one in order to measure again both beam emittance and in a dispersive section energy spread. Further quadrupole doublets will be used in the two straight sections behind the analyzing magnet to increase the β-function by at least two orders of magnitude before stopping the beam in two separate dumps. Thus the damage of the dump windows can be avoided.

3.3 The Linac Module

Each of the four linac modules houses 8 s.c. cavities of the TESLA type [5], which is an approx. 1 m long 9-cell stiffened π-mode standing wave structure operating at 1.3 GHz. The cavities are assembled as a string. They have an input coupler and a HOM coupler at one end and only a HOM coupler at the other end of each. This string is followed by a beam position monitor [9] and a s.c. quadrupole doublet whose beam tube acts as an additional HOM absorber. Each quadrupole has correction coils which can be used as steering coils and for the compensation of potential quadrupole vibrations.

Every s.c. cavity has its own helium vessel and the whole string is supported by a long helium gas return pipe. Operating temperature is 1.8 K; at an unloaded quality factor of $Q_0 = 3\times10^9$ the estimated heat load for the complete TTF linac is approximately 60/60/500 W at 2/4.5/70 K. The first module will be equipped with a large number of temperature sensors and two vibration detectors per cavity. Input and HOM couplers as well as rf windows will have rf pickups. Alignment during cool down will be monitored.

3.4 500 MeV Experimental Area

The high energy beam analysis area is located behind the last cryomodule and its terminating feed can. It serves as a room to measure the relevant beam parameters, i.e. beam position, beam size and emittance, beam energy and spread, beam current and transmission through the linac, bunch length and shape. Some parameters will be measured as a function of the bunch number in the 800 μs bunch train, others as an average over some part of it or for a series of trains. In a first step standard beam diagnostics (wire scanners, screens and striplines) will be used while commissioning the TTF linac. The extensive use of OTR screens is foreseen. Space for testing new diagnostic tools developed for TESLA also will be provided. Two beam dumps complete the whole TTF linac set up.

4 OUTLOOK

At present the commissioning of the TTF infrastructure is almost finished. Two prototype cavities have been used. The first six s.c. cavities will be at DESY this summer so that the processing of it can start soon. The assembly of 8 cavities as a string is scheduled for early 1995 and the first cold test for late spring. The injector assembly starts at Saclay in the beginning of next year. After successful tests it will be delivered to DESY to allow beam tests with the first cryomodule before end of 1995.

5 REFERENCES

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