THE TESLA TEST FACILITY STATUS REPORT

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Abstract

The TESLA Test Facility and Linac, under construction at DESY by an international collaboration is an R&D test bed for the superconducting cavity variant of the TeV scale future linear colliders. The TTF will include capability for processing and measurement of 1.3 GHz superconducting accelerating structures, the cryogenics, power, diagnostics, injector, and other support system appropriate to implementing a 500 MeV test Linac. The main body of the TTF Linac will consist of four cryomodules, each containing eight 1 meter nine-cell cavities. The base accelerating goal is 15 MV/m. Two injectors are planned, both with an average pulse current of 8 mA. The first (less demanding) will provide the 8 mA with a 216 MHz structure; the second which will be necessary for HOM measurements will need to operate with a bunch charge of 5×10^{10} at 1 MHz for 800 bunches. Beam analysis areas will be provided for study of both injected and high energy output beams. Overview and status of the facility, Linac design, and proposed experiments will be given.

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 an 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.

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	3 µm
Beam Size, Injection	260, 60 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 on the injector. The two injectors planned for the TTF will provide the macro pulse current, length and repetition rate planned for TESLA 500; one will provide the design bunch charge. Beam sizes intended for TESLA 500 with 10 GeV injection will not be realized in 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 impossible to check.

What the TTF Linac does check is the achieved gradient [4] including High Peak Power processing [5], the cavity construction and processing techniques [6], and the design of input and HOM couplers. The RF control of multi-cavity systems will be developed and tested under real conditions (Lorentz force detuning, microphonics) [7]. The vacuum failure recovery potential can be studied and a cryostat design [6,8] can be tested under cryogenic operation. The possibility of dark current is of interest as well as an energy and position feedback system. Alignment and its stability [9] can be checked using position monitors and BPM systems [10]. A first iteration on projected system costs should be possible.

Measurements of Q_0 and HOM (both by calorimetric method) are not easy but appear possible. HOM and wake field measurements require the high bunch charge of injector II. Transverse wake measurements are possible with the beam far of axis [11]. Cavity alignment measurements via wake fields will be attempted but may prove difficult. The schedule for injector II will be critical for much of this program. The TTF Linac program will not check out the sensitivity needed for TESLA 500 such as vibration sensitivity and emittance growth.

The TTF Linac

The TTF Linac, as it is shown in Fig. 1 with injector I, 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.

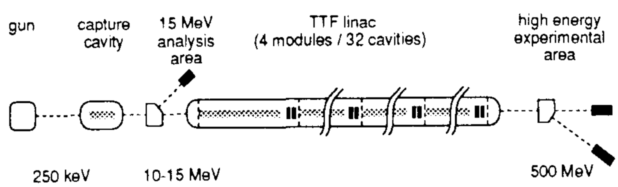

Fig. 1: Schematic layout of the TTF Linac. The overall length of the installation at DESY amounts to ≈85 m; the drawing is not to scale.

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 x 10^{10} electrons). In its initial form, injector I [12] will operate with the parameters as shown in Tab. 1, first column TTF Linac. 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 which is not required for the TTF program.

The warm part of injector I starts with a grid controlled thermionic gun as the source; the anode voltage is 40 kV. The produced bunches (2.3x10^8e$^-$ in 50 deg at 216.7 MHz) are injected into a 1 m long electrostatic preacceleration tube and accelerated to 250 keV. Bunch compression is performed by means of a 6^{th} subharmonic buncher cavity (SHB). From the 250 keV energy then one standard 1 m long nine-cell TESLA cavity finally increases the electron beam energy to above 10 MeV.

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 (β = 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 [13]. 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 and an energy analyzing dipole magnet.

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 along the Linac. This 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. Due to the mentioned rf-focusing the matching to the first cell of the lattice is strongly disturbed. Nevertheless, detailed beam optic calculations achieved a perfect matching with a β-function equal to the cell length of ≈12 m (module length) and provide 90 deg phase advance per cell.

Starting with this β-function at the end of the Linac, the acceleratedd electron beam (now 500 MeV) has to be transported through the high energy beam analysis area to the beam dumps. One more quadrupole doublet will be used together with the last superconducting one in order to optimize both beam emittance and in a dispersive section energy spread measurements. Further quadrupole doublets in the two straight sections behind the analyzing magnet increase the β-function by at least two orders of magnitude before stopping the beam in two separate dumps.

The Linac Module

Each of the four Linac modules houses 8 s.c. cavities of the TESLA type [6], 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 [10] 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 $Q_0 = 3 \times 10^9$ the estimated heat load for the four TTF Linac modules 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.

The rf power source, one 5 MW klystron for 16 s.c. cavities and therefore one half of the TTF Linac, has been already commissioned [14]. The necessary macro pulse repetition rate of 10 Hz at pulse lengths of 2 ms is available at the desired power. At present, tests of warm components of the rf distribution such as rf windows and circulators are made.

500 MeV Experimental Area

The high energy beam analysis area is located behind the last crymodule and its terminating end cap. 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.

First Results and Outlook

At present the commissioning of the TTF infrastructure i. e. a chemical etching facility, a high pressure rinsing station and a preparation area / clean room [15] is almost finished. Two prototype test cavities have been used to commission the cavity processing. After a chemical etching and a high pressure rinsing (≈100 bar) both cavities (RRR = 250) had excellent quality factors at low fields ($Q_0 = 3 - 5 \times 10^{10}$). In preliminary results one cavity reached a cw field gradient of 16 MV/m (at $Q_0 = 2 \times 10^{10}$) while the other one was limited close to 10 MV/m (at a clearly reduced $Q_0 \approx 3 \times 10^9$). Both cavities are limited by quench events. High peak power processing could flaten out the Q_0 vs. E behaviour of one of the two cavities.

The first six s.c. cavities, planned for TTF cryomodules and equipped with real input and HOM couplers, 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 I 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 the end of 1995.

References

[1] The Tesla R&D effort (TESLA = TeV Elektron Superconducting Linear Accelerator) is being carried out by an international collaboration. A number of institutions have joined the collaboration and include IHEP Beijing, TU Berlin, CEN Saclay, CERN, Cornell, TH Darmstadt, DESY, TU Dresden, Fermilab, Univ. Frankfurt, INFN Frascati-Milano-Rom, KFK Karlsruhe, LAL Orsay, IPN Orsay, SEFT Finland, UCLA, Univ. Wuppertal.

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