THE TESLA TEST FACILITY (TTF) LINAC – A STATUS REPORT

H. Weise, for the TESLA Collaboration, Deutsches Elektronen-Synchrotron DESY,
22603 Hamburg, Germany

Abstract

The TESLA Test Facility (TTF) 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 main body of the TTF Linac will consist of four cryomodules, each containing eight 1 meter long nine-cell cavities made from bulk niobium and operated at L-band (1.3 GHz) frequency. The base accelerating goal is 15 MV/m. While a first injector is going to be installed in 1995 and will provide 8 mA beam current within 800 μs long macro pulses at 216 MHz bunch repetition rate, a second injector based on a BNL like RF-gun combined with a standard TESLA cavity as preaccelerator and with a bunch compressor is under development. This injector will need to operate with a bunch charge of 5×10^{10} electrons at 1 MHz bunch repetition rate; the macro pulse length is again 800 μs and the injector output energy approximately 20 MeV. Overview and status of the linac construction will be given. Plans for the future use of the TTF Linac are presented.

I. INTRODUCTION

An electron-positron collider with a center of mass energy of 500 GeV and luminosity above 10^{33} cm $^{-2}$sec^{-1} should be considered as a possibility for the next accelerator facility after the LHC. This is a widespread consensus within the high energy physics community. Such a collider would provide for top analyses via $t\bar{t}$ production and discovery reach up to a Higgs mass of $\approx$350 GeV.

Worldwide, there are groups pursuing different linear collider design efforts. Several of these R&D groups plan to have working prototype test facilities in the 1997 time scale, this in order to establish well-developed collider designs. The TESLA activity [1] is one of these R&D efforts, differing from the others in its choice both of superconducting (s.c.) accelerating structures and of low operation frequency (1.3 GHz).

The TESLA Test Facility (TTF) is to be located at DESY, with major components flowing in from the members of the collaboration. The facility includes infrastructure to prove the feasibility of reliably achieving acceleration gradients above 15 MV/m in a series production. And the TTF has also to show that the in a LINAC test string (32 s.c. cavities) assembled accelerating structures can be successfully operated; this with the help of auxiliary systems (couplers, frequency tuners, cryogenics) to accelerate an electron beam to 500 MeV.

II. THE 500 MeV TTF-LINAC

In Fig. 1 (see next page) a plan view of the TTFL layout is shown. Being located in one of the DESY experimental halls the linac is within an approximately 100 m long shielded enclosure. From right to left an injector including its gun, a capture cavity, and a diagnostic section, is followed by a first cryomodule housing 8 s.c. cavities. A warm section allows for a later installation of a magnetic bunch compressor (see below, outlook) preceding another three cryomodules. The linac facility is finally completed by a diagnostic area which will be used extensively for beam experiments [2].

The operating parameters of the TTFL are given in Tab. I where the two columns Inj I/Inj II already list two scenarios for different injectors.

Table I
TTFL operating parameter.

Parameter	TTFL	
Linac Energy	500 MeV	
RF frequency	1.3 GHz	
Accel Gradient	15 MV/m	
Q_0	3×10^9	
# Cryo modules	4	
ΔE/E single bunch rms	$\approx 10^{-3}$	
ΔE/E bunch to bunch rms	$\approx 2 \times 10^{-3}$	
Bunch length rms	1 mm	
Beam current	8 mA	
Beam macro pulse length	0.8 ms	
Lattice β typical	12 m max	
	Inj I	Inj II
Injection Energy	10 MeV	20 MeV
Emittances (x/y), $\gamma\sigma^2/\beta$	$\approx 5\mu$m	$\approx 20\mu$m
Beam size σ, end of linac	250μm	500μm
Beam size σ, injection	1.7 mm	3.5 mm
Bunch frequency	217 MHz	1MHz
Bunch separation	4.6 ns	1μsec
Particles per bunch	2.3×10^8	5×10^{10}

In the first stage of installation the injector area includes a thermionic electron gun [3], a subharmonic prebuncher, the s.c. capture cavity, focusing lenses, and beam diagnostic equipment. The capture cavity is identical to one of the nine-cell structures (see Tab. II below) in the main linac. With its gradient of 15 MV/m the injected 250 keV electron beam will be accelerated to energies above 10 MeV. In the future, Injector I will be replaced by the high bunch charge Injector II [4] based on a laser driven rf gun. This injector comes close to the requirements of the TESLA Linear Collider electron source (5×10^{10} electrons per bunch, $\epsilon_n = 1\ \pi\ mm\ mrad$). The new installation will be located in the same injector area but needs some additional space for the laser and for the klystron/modulator driving the rf electron gun.

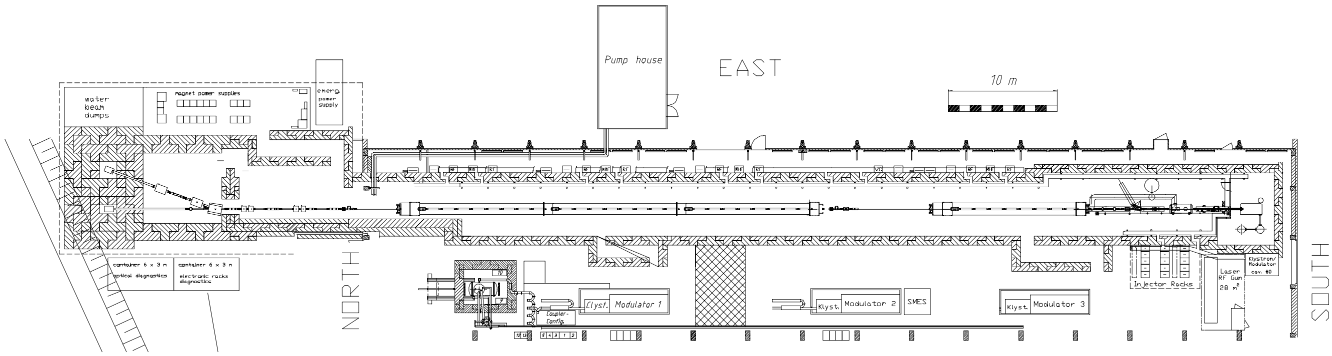

Figure. 1. Plan View of the TESLA Test Facility Linac Layout.

Four cryomodules, each 12.2 m in length, comprise the main body of the linac. Each module contains eight nine-cell π-mode cavities and a quadrupole package. Thus, the beam optics is basically a periodic lattice with a cell length being identical with the module's length; the phase advance in the modified FODO lattice (the quadrupoles come in pairs) is $\pi/2$; matching to the lattice is performed by means of two triplet magnets. Depending on the finally achieved accelerating gradient (15 - 25 MV/m) the energy gain per cryomodule will be between 120 and 200 MeV. Each cavity has a RF power input coupler, two higher-order-mode (HOM) output couplers, a RF fundamental pick up, and a frequency tuning mechanism. Selected parameters of the cavities are given in Tab. II.

Table II
RF cavity parameters for the TTFL

Frequency	1.3	GHz
Cells per cavity	9	
Cavity length	1.036	m
Iris radius	35	mm
R/Q	1011	ohms/cavity
E_{peak}/E_{acc}	≈ 2.0	
RF power @ 25 MeV/m	206	kW/m
HOM k_{long}/cavity	8.5	V/pC (σ_z = 1 mm)
HOM k_{trans}/cavity	18	V/pC/m

The quadrupole package includes a superferric quadrupole doublet, transverse steering coils (two pairs, one each for permanent corrections and for vibration control), a transverse beam position monitor (cylindrical rf cavity), and a HOM absorber. Operation temperature of the quadrupole package is 4 K.

Every s.c. cavity has its own helium vessel and the whole string is supported by a long helium gas return pipe. Shielding against the earth magnetic field will be provided. Therefore, an unloaded quality factor of the cavities well above $Q_0 = 3 \times 10^9$ can be reached at operating temperature (1.8 K). The estimated heat load for all four TTFL modules is approximately 115/115/700 W at 1.8/4.5/70 K, this being calculated for a gradient of 15 MV/m and $Q_0 = 3 \times 10^9$. In this calculation the cold/warm transitions for the bunch compressor section are included. The first module will be equipped with a large number of temperature sensors as well as with vibration sensors. Alignment during cooldown will be monitored using optical methods and in addition to this using a stretched wire system. The latter can be used also during linac operation.

RF power for the main body of the linac will be provided by two klystrons and two modulators. Each klystron/modulator will deliver 4.5 MW with a pulse length of up to 2 ms. The first of these two rf power sources has been commissioned successfully [5]. The injector's capture cavity has its own klystron, the needed RF power within the macro pulse is below 100 kW. The rf gun needed for Injector II requires a few MW of RF power. Here it is foreseen to take advantage of a 10 MW klystron (1.3 GHz) which will be developed as a prototype for the TESLA Linear Collider.

The high energy beam analysis area behind the end of the fourth cryomodule 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 long bunch train, others as an average over some part or for a series of trains. In a first step standard beam diagnostics (scanners, screens and striplines) will be used while commissioning the TTFL. The extensive use of optical transition radiation is foreseen. Space for testing new diagnostic tools developed for TESLA will also be provided. Two beam dumps complete the whole TTF Linac set up.

III. FIRST RESULTS AND STATUS

At present, the commissioning of the TTF infrastructure [6] i.e. a chemical etching facility, a high pressure rinsing station, an UHV oven, and a preparation area/clean room is finished. Two prototype test cavities have been used to commission the cavity processing. Now, a complete preparation procedure includes cavity inspection, a first chemical etching, an UHV oven treatment (with Titanium at 1400°C inside and outside of the cavity), Titanium removal by a second etching, frequency tuning, final etching, and high pressure (100 bar) water rinsing. The first series cavity has been finished in mid March.

In Fig. 2 the shown oscilloscope traces represent the remarkable results of a first operation in the vertical test cryostat. The upper trace gives the field gradient as a function of time while the lower one is the measured forward power, both after some

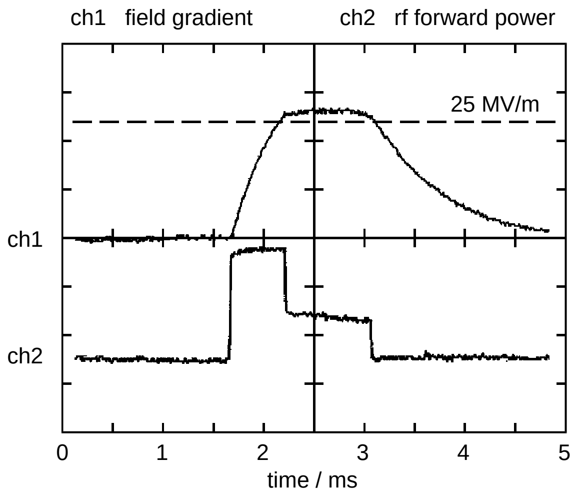

Figure. 2. Field Amplitude and RF Forward Power in the First Series TESLA Cavity.

High Peak Power Processing [7]. The total rf pulse length is 1.3 ms, the first 500 μs are the filling time (exponential groth of the field gradient). At a reduced forward power the gradient was kept above 25 MV/m (the aimed TTF gradient is 15 MV/m) until after 800 μs the exponential decaying gradient relates to the switched off forward power. The decay time corresponds to the loaded quality factor; Q_o has been above 10^{10}.

The assembly of the first cryomodule needs 8 s.c. cavities and will start in summer '95. Injector I is going to be installed in fall '95; at present first tests are carried out at Saclay. The cryomodule installation is also planned for fall this year. It includes the warm/cold transitions and the cryogenic supply lines. A temporary beam line with quadrupoles, steerers, and diagnostics stations will take care of the beam transport between the end of the first module and the high energy experimental area. This area will have its main components installed until the end of the year. Thus, commissioning of the first module of the TTFL can take place by the end of 1995.

IV. OUTLOOK

Further milestones in the TTF Linac schedule are the assembly of the cryomodules #2 - #4 in 1996, the installation of these modules and the above mentioned injector II in early 1997, and the final commissioning with beam in summer 1997. Experiments with the beam will be carried out to study the different components of the linac and their influence on the electron beam quality.

Quite aside from its possible linear collider prospects, the TTF Linac is offering unique beam physics features. As a first application in experimental physics the construction of a Free-Electron Laser (FEL) is under discussion. Due to its exceptional capability to maintain high electron beam quality during acceleration for high charge densities, a superconducting linac might be an optimum choice to drive an FEL based on the Self-Amplified-Spontaneous-Emission (SASE) principle which would allow for the production of coherent radiation tunable in the photon energy range up to 200 eV (6 nm). This kind of FEL has no optical cavity, the electron bunch is just travelling through a long undulator and the spontaneous emitted field together with the periodic undulator field causes an electromagnetic potential (the so-called ponderomotive potential). Further downstream in the undulator the electrons are bunched in this periodic potential and then emit coherently. The achievable peak intensities can be extremely high, and they depend directly on the charge density of the electron beam. A detailed description of studies on such a FEL can be found in [8].

References

[1] The TESLA R&D effort (TESLA = TeV Energy 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, Max Born Institut Berlin, CEN Saclay, CERN, Cornell, Univ.Cracow, TH Darmstadt, DESY, TU Dresden, JINR Dubna, Fermilab, Univ.Frankfurt, INFN Frascati, INFN Milano, INFN Roma II, FZ Karlsruhe, LAL Orsay, IPN Orsay, Polish Acad.of Science, IHEP Protvino, SEFT Finland, UCLA Dept.of Physics, Univ.Warsaw, Univ.Wuppertal.

[2] B. Aune, A. Mosnier, Experimental Program with Beam in the TESLA Test Facility, Proc. of the 1994 LINAC Conf., Tsukuba, Japan.

[3] T. Garvey et al., Simulations and Measurements of the TTF Phase-1 Injector Gun, this conference.

[4] E. Colby et al., Design and Construction of High Brightness RF Photo-injectors for TESLA, this conference.

[5] H. Pfeffer et al., A Long Pulse Modulator for Reduced Size and Cost, Proc. 21^{st} Intern. Power Modulator Symposium, 1994, Costa Mesa, CA, USA.

[6] S. Wolff, The Infrastructure for the TESLA Test Facility (TTF) - A Status Report, this conference.

[7] J. Graber, High Gradient Superconducting RF Systems, this conference.

[8] J. Roßbach, Studies on a Free Electron Laser for the TESLA Test Facility, this conference.