Proceedings of the 1995 Workshop on RF Superconductivity, Gif-sur-Yvette, France

TESLA TEST FACILITY: STATUS

B. Aune, for the TESLA Collaboration
DESY, 22603 Hamburg, Germany

Abstract

The TESLA Test Facility (TTF), under construction at DESY by an international collaboration, is an R&D test bed for the superconducting option for future linear e+/e- colliders. It consists of an infracstructure to process and test the cavities and of a 500 MeV linac. The infracstructure has been installed and is fully operational. It includes a complex of clean rooms, an ultraclean water plant, a chemical etching installation and a ultra-high vacuum furnace.The linac will consist of four cryomodules, each containing eight 1 meter long nine-cell cavities operated at 1.3 GHz. The base accelerating field is 15 MV/m. A first injector will deliver a low charge per bunch beam, with the full average current (8 mA in pulses of 800 μs). A more powerfull injector based on RF gun technology will ultimately deliver a beam with high charge and low emittance to allow measurements necessary to qualify the TESLA option and to demonstrate the possibility of operating a free electron laser based on the Self-Amplified-Spontaneous-Emission principle. Overview and status of the facility will be given. Plans for the future use of the linac are presented.

INTRODUCTION

The superconducting option for an electron-positron linear collider of 500 GeV center of mass energy (TESLA) is being studied by an international collaboration [1], in parallel with similar efforts by other groups on various technical solutions. Several prototype tests facilities are now under construction to establish well-developed collider designs.

The TESLA approach uses superconducting structures operating at a frequency of 1.3 GHz and a gradient of 25 MV/m. This choice presents some essential advantages:

- The low rf frequency results in small longitudinal and transverse wake-fields, which permits to loosen the alignment tolerances.
- The high conversion efficiency allows to accelerate a high beam power and to obtain a given luminosity with relaxed constraints on the beam spot size.
- The required peak rf power is low: a 10 MW klystron feeds 32 cavities.
- The long beam pulse (0.8 ms) results in large spacing between bunches (700 ns). This offers advantages at the interaction point as well as for beam dynamics in the linac (possibility of using the first bunch for feedback, suppression of multibunch instabilities with reasonable damping of HOM).

There are several conceptual problems for the collider design resulting from the high beam power and the large number of bunches per pulse, like the positron source, which cannot be of a conventional design, and the damping rings which should be either very long or use a sophisticated technique for injection and extraction.

The technical challenge of TESLA is to operate at very high gradient a large number of cavities (20000) and to realize the linac at a reasonable cost.

The goal of the TESLA Test Facility (TTF), under construction at DESY, is to demonstrate the ability to accelerate a beam with proper qualities through a chain of 32 cavities operating at a field level of at least 15 MV/m and to reach an overall design of cavities, cryostats, couplers and auxiliary systems which leads to important cost reduction.

DESCRIPTION and STATUS

A detailed description of the TTF linac and of part of the infrastructure can be found in the design report [2]. Recent status reports have been presented at the PAC95 for the infrastruture [3] and the linac [4]. The most important features and latest developments are presented in this paper.

Preparation and test of cavities

Fourty nine-cell cavities will be fabricated by several companies, processed and tested at DESY and installed in the linac. At this moment, 13 cavities have been delivered and will be used for the first module and the injector, to be installed by mid-96.

The standard suface preparation sequence is the following:

- Chemical etching (10 µm inside and outside)
- UHV high temperature treatment (1400 C) with Ti getter, resulting in RRR>500
- Chemical etching (30 µm outside, 80 µm inside)
- Tuning
- Chemical etching (20 µm inside)
- High pressure rinsing (100 bar)

High peak power processing can be applied during cold tests (up to 1 MW) if necessary.

The cavities are tested in a vertical cryostat and in addition, when they are equiped with their helium vessel and couplers, in a horizontal cryostat. This second test is an intermediate step before the installation in the accelerating module and should give information about a degradation of performances -if any- between vertical test and the linac. Up to now, five cavities have been extensively tested and very encouraging results have been obtained [5,6]. In particular, gradients above the TESLA design value of 25 MV/m have been obtained in pulsed mode (flat top of 0.8 ms) in vertical tests. One experiment has been performed in horizontal cryostat which showed no degradation of the cavity performance after helium vessel welding and HOM couplers mounting.

The 500 MeV linac

The main parts of the linac are: the injector, a first cryomodule housing 8 cavities, a 12 m long warm section in which a bunch compressor will be later installed, three cryomodules connected in series and a diagnostic area. The main parameters are given in table 1.

Energy	500 MeV
Beam current	8 mA
pulse length	0.8 ms
repet. frequency	10 Hz
Accel. gradient	15 MV/m
Qo	$3x10^9$
Heat load at 2 K	115 W
Number of cavities	32
Number of modules	4
Number of klystrons	2

Table 1 TTF linac parameters

The injector delivers a beam of about 12 MeV. This is necessary for transmission through the first module without quadrupole and in presence of the strong focusing effect of the cavities [7]. It consists of a thermoionic 250 kV source (40 kV gun

followed by an electrostatic column), a 216 MHz (f/6) prebunching cavity and a standard nine-cell SC cavity housed in its own cryostat [8]. This injector gives the TESLA beam current but with a much lower charge per bunch. In a later stage an RF gun giving the full charge per bunch (8 nC at 1 MHz) will replace the thermoionic source [9].
Tests have been performed on different components of the injector (250 kV beam, cryostat, RF system). The 12 MeV beam is expected in April 96.
Four cryomodules, each 12.2 m in length, constitute the main body of the linac. Each one contains eight cavities, a SC quadrupole doublet and a beam position monitor. The liquid helium distribution and cold gas recovery system are incorporated into the cryostat. The cryostat design principle is to make individual accelerating module as long as possible and combine them by strings fed by a single cold box. This should result in low static losses (0.23 W/m at 2K) and important cost reduction [10]. The cavities are suspended to the helium gas return pipe which serves as a reference girder. Each cavity is equiped with its own Ti helium vessel welded around it, the beam tubes and the connections for couplers being inside the insulating vacuum. Alignment of cavities will be monitored using a stretched wire system. The tuning mechanism is actuated by a cold stepping motor.
The first cryostat components (vacuum vessel and cold mass) and the tooling for assembly have been fabricated. Assembly of the string of eight cavities is expected to start in May 96.
The cryogenic system [11] is already used for testing cavities in vertical and horizontal cryostats. Its complete installation for the linac is well underway. The cooling capacity is 100 W at 2K in a first stage, to be increased to 200 W with the help of an additional heat exchanger. Cryogenic operation of the injector cryostat is expected in April 96, the main cryomodule will then be connected when ready.
Cavities, couplers and RF power. The main parameters of the cavities are listed in table 2. Each cavity is equiped with an RF input coaxial coupler, two HOM couplers [12] and an RF pick-up. The input coupler should allow an adjustment of the coupling by a factor of 3 around the design value of 3.10^6 and tolerate a longitudinal displacement during cooldown of up to 15 mm. There is a cold window at 70 K, installed in the clean room, and a window at room temperature. Two models have been studied. RF power tests have been made on components. A complete set-up for conditionning the couplers at full power is now operating, two prototypes couplers were processed up to 1 MW peak power. Two models of HOM couplers exist. Their RF properties have been checked on a Cu 9-cell cavity. Nb version of both models have been tested under high field level on a SC cavity [13]. A nine-cell cavity, equiped with its two HOM couplers reached a field of 18 MV/m in CW in the horizontal cryostat [6].

Frequency	1.3 GHz
Number of cells	9
Coupling	1.87 %
Epeak/Eacc	2
R/Q	1011 Ohms
Effective length	1.036 m
Iris diameter	70 mm
RF power at 25 MV/m	206 kW

Table 2 Parameters of the TTF cavity

RF power for the 32 cavities of the linac will be provided by two klystrons and two modulators, each klystron delivering a power of 4.5 MW with pulse length of up to 2 ms. The first klystron/modulator exists [14] and is extensively used for tests of

cavities, components and couplers. It will also serve as power source for the first module. The power is distributed to the cavities by means of directional couplers. For each cavity, there is a three stub wave guide tuner for impedance matching and adjustement of phase by ± 30 deg. Individual low power circulators are installed on each cavity. All the equipment exists, has been tested and is being installed.
The SC cavity from the injector is fed by a separate 200 kW klystron.

Developments on low level RF control

The bunch to bunch energy dispersion along the entire pulse length should be maintained at a low level in TESLA to avoid emittance dilution due to chromatic effects. A value of 3.10^{-4} is assumed . The beam loading can be ideally compensated by matching the power extracted by the beam to the power supplied by the generator during the pulse. Other perturbations must be compensated for by the low level RF system. The main perturbation comes from the Lorentz force detuning, other are microphonics and cavity parameters variations.
For the injector, an RF control module using self excited loop principle has been realized. Amplitude and phase errors of the cavity field are combined through a vectorial modulator. This module has been successfully tested on the Saclay SC linac MACSE operated in pulsed mode with parameters close to the operating conditions of TTF [15].
For the linac, the low level control system is designed to regulate the vector sum of the 16 cavities. Presently two systems are under development. An analog feedback system applies traditional amplitude and phase control, while a fully digital system employs I&Q control. The goal is to compare the performance of the two systems [16].
In the digital feedback design, the field probe signals are converted to 250 kHz. These signals are sampled at a rate of 1 MHz i.e. two subsequent data points describe I and Q of the cavity field. The I and Q vectors are multiplied by 2x2 matrices to correct for individual measurement phase offsets and to calibrate the gradients. The vector sum is calculated and a state estimator which corrects for the delay in the feedback loop and a Kalman filter which optimizes the state (cavity field) estimate with respect to sensor noise are applied. Finally the set point is subtracted and a time optimal gain matrix is applied to calculate the new actuator setting (I and Q control inputs to a vector modulator). Feed forward is added from a table in order to minimize the control effort.
Prototypes of both systems have been build and tested with single cavities at gradients up to 25 MV/m. It has been demonstrated that both system meet the control requirements of better than 1 degree for the phase and 1% for the amplitude.

Experimental program and future plans

In addition to cavity performance, there are several issues for the TESLA collider which will be tested with the TTF linac [17]. With the low charge injector, the main experiment will concern the beam energy stability during the pulse. Tests can also be performed on some RF effects like the steering due to couplers. With the high charge injector, all effects related to wake-fields will be studied by injecting the beam on axis or off axis. One of the key parameters for TESLA is the fraction of HOM power generated by the beam which is deposited in the 2 K parts. It will be estimated by calorimetric measurements. Studies on dark current acceleration are also planned.
All the parameters of the beam longitudinal and transverse phase spaces will be studied by a large number of monitors under development in different laboratories of the collaboration, the description of which is out of the scope of this workshop.
At the 500 MeV level, it is planned to make a demonstration of feasability of a free electron laser operating in the SASE mode. For this purpose, a bunch charge of 1 nC is necessary, with a normalized emittance of the order of 1 mm.mr and a bunch length

reduced to 0.2 mm by a bunch compressor. These experiments are expected to take place in 1998 [18].
For the longer term future it is planned to double the length of the linac to 1 GeV and to operate a VUV light-source yielding a coherent, very bright beam of photons with wavelength tunable between 20 nm and 6 nm [19].

Conclusion

The complete infrastructure for cavity processing and testing is in operation, excellent results have been recently obtained -exceeding the TESLA design value of 25 MV/m-, most of the linac components exist or are in final stage of construction. A beam through the first eight-cavity module is expected by mid-96. Plans exist to use the facility, extended to 1 GeV, as an intense photon beam source in the year 2000.

References

[1] The TESLA R&D effort is carried out by a number of institutions which includes IHEP Beijing, TU Berlin, Max Born Institute Berlin, Cornell U.,Univ. Cracow, TH Darmstadt, DESY, TU Dresden, DSM/DAPNIA Saclay, JINR Dubna, Fermilab, Univ. Frankfurt, IN2P3/LAL Orsay, IN2P3/IPN Orsay, INFN Frascati, INFN Roma II, INFN Milano, FZ Karlsruhe, INP Novosibirsk, Polish Acad. of Science, IHEP Protvino, SEFT Finland, UCLA Dep. of Physics, Univ. Warsaw., Univ. Wuppertal.
[2] D.A. Edwards ed. : TESLA Test Facility Linac - Design Report; DESY Print TESLA Rep. 95-01
[3] S. Wolff : The Infracstructure for the TESLA Test Facility - A Status Report; Particule Accelerator Conference, Dallas 1995
[4] H. Weise : The TESLA Test Facility Linac - A Status Report; Particule Accelerator Conference, Dallas 1995
[5] W.D Moller : Quest for High Gradients; this workshop
[6] J. Kuzminski : First cold Test of TESLA Cavity in horizontal Cryostat; this workshop
[7] H. Weise : The TESLA Test Facility - A Description of the Superconducting Linac; 4th European Accelerator Conference, London, 1994
[8] R. Chehab et al. : Progress in the Study and Construction of the TTF Injector; Particle Accelerator Conference, Dallas 1995
[9] E. Colby et al. : Design and Construction of High Brightness RF Photo-injectors for TESLA; Particle Accelerator Conference, Dallas 1995
[10] F. Alessandria et al. : Design, manufacture and test of the TESLA-TTF cavity cryostat; Cryogenics Engineering Conference, Columbus, Ohio, 1995
[11] G. Grygiel et al. : Status of the TTF cryogenic system; Cryogenics Engineering Conference, Columbus, Ohio, 1995
[12] K. Koepke : Design of power and HOM couplers for TESLA; Cryogenics Engineering Conference, Columbus, Ohio, 1995
[13] S. Chel et al. : Thermal Tests of HOM Couplers for Superconducting Cavities; 4th European Accelerator Conference, London, 1994
[14] H. Pfeffer et al. : A Long Pulse Modulator for Reduced Size and Cost; 4th European Accelerator Conference, London, 1994
[15] A. Mosnier, Saclay, private communication
[16] S. Simrock, A. Gamp, DESY, private communication
[17] A. Mosnier : Experimental Program with Beam in TESLA Test Facility; 17th LINAC Conference, Tsukuba, 1994
[18] J. Rossbach : Studies on a Free Electron Laser for the TESLA Test Facility; Particle Accelerator Conference, Dallas 1995
[19] A VUV Free Electron Laser at the TESLA Test Facility at DESY - Conceptual Design Report; DESY Print TESLA-FEL 95-03