RESULTS FROM THE DESY TESLA TEST FACILITY

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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 infrastructure to process and test the cavities and of a 390 MeV linac. The infrastructure 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 three cryomodules, each containing eight nine-cell cavities operated at 1.3 GHz. The accelerating gradient should be of at least 15 MV/m, with a Q of $3x10^9$. The injector delivers a beam of 10-15 MeV, it has been installed and commissioned. The first module is in place, a 140 MeV beam is expected in June 97. An overview of the facility and results of the tests are given in this paper.

1 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.

The TESLA approach uses superconducting structures operating at a frequency of 1.3 GHz with a gradient of 25 MV/m and a quality factor of $5x10^9$ at T=2K. This choice presents advantages for the design of the collider, linked to the low rf frequency and the high AC-to-beam power efficiency of a SC linac. Many well-separated bunches are accelerated in a long rf pulse, the tolerances are relaxed compared to other approaches. Another characteristic of this choice is the low peak rf power needed and the availability of klystrons [2].

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

The TESLA Test Facility (TTF) is under construction at DESY with major components flowing in from the members of the TESLA collaboration. Its aim is to demonstrate the ability to accelerate a beam with proper qualities through a chain of 24 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 costs competitive with the other approaches based on conventional structures.

2 INFRASTRUCTURE AND CAVITY PERFORMANCE

2.1 Cavity processing

Obtaining a useable gradient of 25 MV/m or more in 9-cell cavities requires that one can overcome the field limitations: quenches and field emission. The quench limit is due to heat dissipation in local defects, the solution to the problem is to use very high purity Nb with increased thermal conductivity. The field emission, mainly due to the presence of micron sized particules on the surface , requires extreme cleanliness in the processing and installation of the cavities.

The infrastructure for cavity preparation is composed of a complex of clean rooms (from class 10000 to class 10), a chemical etching facility and ultra-clean water supply. A UHV furnace is used to improve the niobium material properties via heat treatment at 1400 C in presence of Ti gettering. High pressure water rinsing (100 bar) is applied at the last step of cavity preparation.

2.2 Cavity performance

The cavities are first tested in a vertical cryostat in which high peak power processing (up to 1 MW in short pulses) can be applied. Temperature mapping is also available.

After welding of the helium tank and mounting of couplers and tuner, a cold test is performed in a special horizontal cryostat, where the complete accelerating system is tested in the TTF pulsed mode (field flat top of 0.8 ms). The behavior of the couplers, the tuning mechanism and other components are checked before the cavity is installed in the linac.

Twenty cavities have been tested in the vertical cryostat, nine of them in the horizontal one. A complete summary of the tests is given in a separate paper [3].

The specifications for TTF have been exceeded in the majority of these tests. In several cases, a field of 25 MV/m has been obtained in cw mode and up to 30 MV/m in pulsed mode. According to the measurements in the horizontal cryostat, the average field in the first module should exceed 15 MV/m.

3 THE TTF LINAC

The experience gained on the TTF linac will feed directly into the TESLA collider design. There are a number of aspects in which both designs are similar. A detailed description of the linac can be found in [4].

The main components 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, two cryomodules connected in series and a diagnostic area. The main parameters of the linac are given in table 1.

Table 1 TTF linac parameters

Energy	390 MeV
Beam current	8 mA
rms energy spread	2×10^{-3}
pulse length	0.8 ms
repetition frequency	10 Hz
Accelerating gradient	15 MV/m
Quality factor Qo	3×10^{9}
Heat load at 2 K	86 W
Number of cavities	24
Number of modules	3

3.1 Injectors

The TESLA design values for the beam current will be reached in two stages: the 1st injector delivers 8 mA with a bunch repetition frequency of 216 MHz and a bunch charge of 37 pC, while the 2nd one will give the same current with a frequency of 1 MHz and a bunch charge of 8 nC. In both cases, the rms bunch length is 1 mm.

Injector I delivers a beam of at least 10 MeV. 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 and powered by a 200 kW klystron. A beam analysis station allows the tuning of the injector linac.

Injector II will be composed of an rf gun followed by the same SC cavity giving a total energy of about 20 MeV. A bunch compressor will be used at this level to obtain the bunch length of 1 mm. Two models of rf gun are under development: one for the full TESLA bunch charge (8 nC) and another one optimized for very low emittance (~1 mm.mr) at reduced charge (1 nC) for FEL experiments. They both use a 1.5 cell 1.3 GHz cavity powered by a 5 MW klystron and a Cs_2Te photocathode. The installation will permit the use of injector I or injector II alternatively.

3.2 Cryomodules

Three cryomodules, each 12.2 m in length, constitute the main body of the linac. Each one contains eight cavities, and a 4 K package including a superferric quadrupole doublet, steerers, a beam position monitor (cylindrical RF cavity, TM110 mode) and a HOM absorber. The liquid helium distribution and cold gas recovery system are incorporated into the cryostat. The cryostat design principle is to make the individual accelerating modules as long as possible and combine them to strings fed by a single cold box. This should result in low static losses (typically 0.2 W/m at 2K) and important cost reduction. The cavities are suspended from the helium gas return pipe which serves as a reference girder. Each cavity is equipped with its own Ti helium vessel welded around it, the beam tubes and the connections for couplers being inside the insulating vacuum.

3.3 Cavities

The 9-cell cavities are made of 2.8 mm, high RRR niobium. In addition to the standard fabrication technique, stiffening rings between adjacent cells have been added in order to reduce the detuning due to radiation pressure. With this technique a detuning parameter of $\sim 1\ \mathrm{Hz/(MV/m)^2}$ is obtained. The main parameters of the accelerating cavity are given in table 2.

A tuning mechanism acts on the overall length of the cavity, driven by a stepping motor located in the isolation vacuum. The tuning range is 800 kHz, corresponding to about 10^6 motor steps.

Table 2 Parameters of the TTF cavity

Frequency	1.3 GHz
Number of cells	9
Active length	1.036 m
Cell to cell coupling	1.87 %
Iris diameter	70 mm
Epeak/Eacc	2
R/Q	1010 Ohms
long. loss factor (σ=1mm)	8.5 V/pC
RF power at 25 MV/m	206 kW
External Q	3×10^{6}

3.4 Couplers

Two versions of coaxial input coupler have been developed. The coupler consists of a cold part mounted on the cavity in the clean room and closed by a 70 K ceramic window, and a warm part mounted after the installation of the cavity in the cryomodule. This part contains a coaxial to wave-guide transition and a second ceramic window at room temperature. An adjustment of the coupling by a factor of 3 around the design value is provided by moving the inner conductor. Flexibility for axial displacement during cooldown of up to 15 mm is achieved via inner and outer conductor bellows.

The HOM couplers are mounted at both ends of the cavity with a nearly perpendicular orientation. A notch filter is incorporated for the fundamental mode rejection. Two types have been developed, a welded version and a demountable one. Both have been tested at high field level during the horizontal cryostat tests and the damping of the most dangerous modes has been measured. The Q's of the dipole modes are sufficiently low for the designed multibunch instability in TESLA.

3.5 RF system

RF power is provided by a 5 MW klystron which can feed 16 cavities. The power distribution is a linear system branching off identical amounts of power for each cavity from a single line by means of directional couplers. Individual three stub wave guide tuners for impedance and phase matching of each cavity provide the possibility of adjustment of phase by ± 30 deg. Individual low power circulators are installed on each cavity.

The low level RF control system must keep the fluctuations of the accelerating field (vector-sum of 16 cavities) to a low level to reduce the uncorrelated contributions to energy spread. The major sources of field perturbations are caused by fluctuations of the resonance frequency of the cavity and by fluctuations of the beam current. A digital feedback system will provide control of the accelerating field [5].

4 STATUS AND RESULTS

All the components for beam acceleration through the first cryomodule (140 MeV) are installed, the first beam is expected at the beginning of June 97.

4.1 Injector

The complete injector has been installed and tested [6]. During this first experiment the accelerating field in the capture 9-cell cavity was limited to 14 MV/m by strong field emission, although in the previous horizontal test a field of 18 MV/m was obtained. High power processing will be applied during the next run. The designed characteristics for the beam have been obtained (table 3) with a very good stability and reproducibility. The analog RF control system has been extensively tested with and without beam [7]. The expected values for amplitude and phase stability have been demonstrated: $\pm\ 4.10^{-4}$ and $\pm\ 0.1°$ peak to peak.
In addition the 12 MeV beam has been used for beam monitors developments: profile and emittance using an OTR station associated with an intensified gated camera, calibration of BPM, beam current measurement and loss monitoring system using toroid transformers.

Table 3 Injector Test Results

	Design	Measured
Beam current	8 mA	8 mA
Energy	> 10 MeV	12 MeV
rms energy spread	100 keV	< 100 keV
pulse length	0.8 ms	0.8 ms
bunch rep rate	216 Mhz	216 Mhz
bunch width (gun)	640 ps	600 ps
rms norm emitt.	5 mm.mr	3-4 mm.mr

4.2 Cryomodule and cryogenic system

The connection and pre-alignment of the string of 8 cavities and the SC quadrupole doublet has been made inside the clean room. The string is then moved on a rail outside the clean room. The complete mounting of the cryomodule has been achieved in 8 weeks, as scheduled. This first module has been equipped with a large number of temperature sensors as well as vibration sensors. Particular care has been taken in the alignment procedure. It has been found that with the present design, an accuracy better than 0.5 mm can be achieved for the cavities, as required from the TESLA specifications. Some improvements will be made for the following cryostat which will permit an accuracy of 0.2 mm. The position of the cavities will be monitored during cool-down and steady state operation with a system of stretched wires and wire position monitors [8], each cavity being equiped with 4 monitors.

The cryogenic system is fully operational, it has been used in routine operation during the injector tests.

4.3 RF system

The existing 5 MW klystron and modulator will be used to power the 8 cavities of the first cryomodule. A new multi-beam klystron is under development by Thomson which will deliver a power of 10 MW with an efficiency of 70%. The first tube is expected by the end of 97, it will be used to power the 24 cavities.

The digital low level RF control system has been extensively tested during experiments in the horizontal cryostat. The design performances of the system have been demonstrated under high field operation where the detuning of the cavity due to Lorentz forces is important. The data acquisition system for amplitude and phase of RF signals based on a 1 MHz sampling, digital in-phase and quadrature detection system has been used during the injector tests to monitor the field stability.

4.4 Beam lines and monitors

The complete beam line from the injector to the high energy beam analysis station is installed and under vacuum. All the components have been vacuum fired and carefully cleaned, the connections in the tunnel being made under the protection of a local clean room. The pressure in these lines is in the range of 10^{-10} mbar.

The complete beam monitoring system, including data acquisition is installed, some monitors have been tested using the 12 MeV beam from the injector.

5 SCHEDULE AND EXPERIMENTS

5.1 First module, injector I

Starting in June 97 the experimental program with the beam accelerated through the first module includes:

- Measurements of cavity performance in linac environment.
- Cryostat behavior: losses, alignment of cavities.
- RF to beam power transfer: test of the rf control system.
- RF steering effect of couplers by measuring the beam displacement for various rf phases.
- Measurement of dark current.

5.2 Modules 2 and 3, injector II

In 98 will be installed the high charge injector and two more modules, giving an energy of at least 400 MeV. This equipment will permit to evaluate some of the key parameters for the collider design, like:

- HOM power deposited at T=2 K and choice of absorber at intermediate temperature.
- Cavity offset measurement with HOM power on dipole modes.
- short range and long range wakefields evaluation, damping of HOM with beam on axis and off axis.

In 99 an ondulator will be installed to demonstrate the feasibility of a free electron laser operating in the SASE mode. A bunch compressor after the 1st module will reduce the bunch length to 0.2 mm.

5.2 Future plans

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 tuneable between 20 nm and 6 nm.

The linac extension would be composed of optimized versions of the components of TESLA.

6 CONCLUSION

The first stage of the TTF linac is now finished, the injector has delivered a 12 MeV beam, the beam experiments at the level of 140 MeV will start in June 97. A test set up for the FEL gun will be operated at DESY starting in September 97, the final tests for the TESLA gun are being accomplished at Fermilab. Experiments on free electron laser are schedule for 99.

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 Univ., Cracow Univ., TH Darmstadt, DESY, TU Dresden, DSM/DAPNIA Saclay, JINR Dubna, Fermilab, Frankfurt Univ., 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, Warsaw Univ., Wuppertal Univ.

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