Status of the TESLA Test Facility Linac

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

Abstract

The TTF linac, a major effort of the TESLA Test Facility, is now in the installation phase. The components have been built by an international collaboration and are presently set up at DESY/Hamburg. A first injector has been installed and tested since the beginning of the year and can provide 8 mA beam current within 800 µs long macro pulses at 216 MHz bunch repetition rate. The first cryomodule containing 8 superconducting cavities is expected for spring 97. The accelerated electron beam (140 MeV) can then be transported to the high energy experimental area which is presently being set up and contains all necessary beam diagnostic elements. The commissioning of all beam transport and diagnostic components at injector energy (10-15 MeV) will be done before the module installation. It will be followed by the commissioning of the RF control system needed to manage the individual phases and amplitudes of the superconducting cavities. An optimized operation can be expected before the installation of the remaining linac modules. Plans for the future use of the TTF Linac as a driver for a Self Amplified Spontaneous Emission Free-Electron Laser are mentioned.

Introduction

Within the high energy physics community there is a widespread consensus that an electron-positron linear collider with a center of mass energy of 500 to 1000 GeV and luminosity above 10^{33} $(cm^2 sec)^{-1}$ should be considered to provide for top analyses and for discovery reach up to a Higgs mass of more than 350 GeV. Therefore several test facilities are underway to develop key technologies. Small beam emittances, and especially beam sizes at the interaction point of such a linear collider have to be achieved with very large average power beams. Thus a collider linac becomes also most attractive for next generation synchrotron radiation sources.

One of the approaches to a 500 GeV collider is the usage of superconducting (s.c.) accelerating structures. The international TESLA [1] collaboration is following this approach. A test facility, located at DESY with major components flowing in from the members of the collaboration, is trying to establish a well-developed collider design.

The facility includes infrastructure to prove the feasibility of reliably achieving accelerating gradients above 15 MV/m in series production. The TESLA linear collider would rely on superconducting structures operating at 1.3 GHz with a gradient of 25 MV/m and an unloaded quality factor of $5x10^9$ at T=2K. Besides cavity preparation and testing, the TESLA Test Facility (TTF) is also going to show the successful operation of these accelerating structures assembled in a test string. An electron beam will be accelerated in modules of 8 s.c. cavities each.

The TTF Linac

The experience gained on the TTF linac will feed directly into the TESLA linear collider design. Therefore both designs are similar with respect to a number of aspects, e.g. cavity and cryostat design, but also as many beam parameters as possible. A very complete description of the TTF Linac can be found in [2].

The main components of the linac are the injector, a first cryomodule housing 8 s.c. cavities, a 12 m long warm section including beam diagnostics, and further cryomodules followed by a beam analysis area. The main parameters of the linac are listed in Table 1.

Table 1 TTF Linac Parameters

Energy	390 MeV
Beam current	8 mA
Pulse length / rep.frequency	0.8 ms / 10 Hz
Accelerating gradient	15 MV/m
Quality factor Q_0	3×10^9
Heat load at 2K	86 W
Number of cavities/modules	24 / 3

The installation of the linac is being carried out in different stages which each allow the acceleration of the beam followed by the delivery to the diagnostic area with its high energy beam dumps. Since the TESLA design values for the bunch charge and beam current rely on an RF gun which is still in the development and test phase, the first stage of installation starts with an injector consisting of a thermionic 250 kV source (40 kV gun, grid controlled, followed by an electrostatic column), a 216 MHz subharmonic prebuncher, a standard nine-cell s.c. cavity, and a 15 MeV beam analysis station. The s.c. cavity is installed in its own cryostat and powered by a 200 kW klystron.

The 10-15 MeV injector beam is injected into the first cryomodule in which acceleration up to about 140 MeV will be possible. Two quadrupole triplets are used for matching the transverse phase space.

Cryomodule and Cavities

The first cryomodule is a standard unit and also a prototype for the large collider. Similar modules would constitute the main body of the TESLA linac. Each one contains eight nine-cell π-mode cavities, and in the case of TTF a s.c. quadrupole doublet combined with a cold resonant cavity beam position monitor. 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 [3]. The cavities are suspended from the helium gas return pipe which serves as a reference girder. Each cavity is equipped with its RF power input coupler, two higher-order-mode (HOM) output couplers, an RF fundamental pick up, and a frequency tuning mechanism.

The individual cavities have their own Ti helium vessel welded around it, the beam tubes and the connections for the RF couplers being inside the insulating vacuum. Shielding of the cavity against the earth magnetic field will be provided to allow for high unloaded quality factors, i.e. low static heat losses.

The quadrupole package includes a superferric quadrupole doublet, transverse steering coils (two pairs, one each for permanent corrections and for vibration studies/control), the transverse beam position monitor (cylindrical RF cavity, TM110 mode) mentioned above, and a higher order mode absorber. Operation temperature of the quadrupole package is 4 K.

The first module will be equipped with a large number of temperature sensors as well as vibration sensors. Alignment during cooldown will be monitored using optical methods and in addition to this using a stretched wire system [4]. The latter can be used also during linac operation.

The beam transport system between the end of the first module and the diagnostic area consists of four almost equal sections, each of them 12 m in length, and including a view screen, a beam position monitor (stripline or resonant cavity), a quadrupole doublet, and a pair of steerers. For pumping, three titanium sublimation pumps (1000 l/s) and three smaller ion pumps (80 l/s) per section are used.

Beam Analysis Area

The beam anlalysis area behind the end of the last cryomodule serves as a room to measure relevant beam parameters, i.e. beam position, beam size and emittance, beam energy and energy 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 of the train, or for a series of it. The extensive use of optical transition radiation (OTR) is planned.

The beam analysis area has a length of about 15 m. It consists of two straight sections. One is in line with the linac axis, the other one is a dispersive section behind a high energy spectrometer dipole magnet. Both sections contain quadrupole doublets and wire scanners, view screens (OTR), and stripline beam position monitors. Toroids are used along the linac to measure the charge transmission up to one of the two beam dumps which complete the whole TTF Linac set up.

Second Stage of Installation

In a second stage of the set up an RF gun will replace the above mentioned thermionic source. Two of the laser driven guns are in the test (TESLA gun, high 8 nC bunch charge) and construction phase (FEL gun, reduced 1 nC bunch charge, very low 1mm mrad emittance) respectively. Both guns use a 1.5 cell 1.3 GHz cavity fed by a 5 MW klystron. The photocathode will be made from Cs_2Te. The installation will permit the use of the presently installed injector or one of the two RF guns alternatively.

The second stage also includes the replacement of the first 12 m long beam transport section by a magnetic bunch compressor and its diagnostics. The next two sections of the beam line will be exchanged by cryomodules connected in series. The fourth section will take up three undulator modules [5]. The experimental area stays almost unchanged. At the above mentioned gradient of 15 MV/m the achievable energy is then 390 MeV.

Present Status

Injector

The complete 250 keV beam line has been installed at DESY. The design beam characteristics have been obtained and tests on different components and monitors have been performed [6]. Table 2 gives the results of some measurements.

Table 2 Injector Test Results

	Design	Measured
Beam current	8 mA	>8 mA
Energy	250 keV	250 keV
Pulse length	0.8 ms	0.8 ms
Micro pulse width	<640 ps	600 ps
Micro pulse rep.rate	216 MHz	216 MHz
rms emittance	<5 mm mrad	3-4 mm mrad

After the successful test of the horizontal cryostat, the s.c. capture cavity has been installed inside. At present, first RF tests of the cavity are carried out. The first cold test is scheduled for 9/96 and should reproduce the previously reached gradient of 17 MV/m. The installation of the capture cavity and the following matching section is planned for 10/96.

Cavity and Coupler Performance

To date, 15 cavities from different manufacturers have been delivered. Tests have been performed on 13 of them [7]. Very encouraging results have been obtained. In cw mode, heat treated cavities reached fields in excess of 20 MV/m with Q_0 higher than $5x10^9$. The best result is a field of 26 MV/m with a Q_0 of $3x10^{10}$. The same cavity was just measured in the horizontal test cryostat in pulsed mode (200 kW input power) with its final RF couplers mounted: a degradation of the gradient was not observed. For some cavities, however, the quench field is around 12 MV/m (cw); an increase of the surface resistance with field appears, but no field emission has been observed. Investigations are underway to understand if this is caused by material problems or by the production technique.

Cryostat, Cryogenic System

The complete tooling for assembling the 8 cavity string and the quadrupole package in the cryostat has been installed at the end of 95. Minor modifications will be done this fall. The vacuum vessel and other components of the cryostat have been delivered. The vacuum vessel, made from carbon steel, has been demagnetized in its final position. A complete test mounting with one cavity and the quadrupole package has been performed. It has been checked that the cavities can be aligned with an accuracy of 0.2 mm. The cryogenic system will be fully operational in fall this year. The presently installed cooling capacity amounts to 100 W at 2 K.

RF System

RF power for the linac will be provided by two klystrons and two modulators, the first and already extensively used source delivering up to 5 MW at a pulse length of 2 ms. The second klystron has been designed for 10 MW at equal pulse length. It is expected for 1997.

While the wave-guide system for module #1 is installed, the low level RF control system is still under test on cavities in the horizontal test cryostat. The bunch to bunch energy dispersion must be reduced to very low level ($3x10^{-4}$ is assumed for TESLA 500). The control system will regulate the vector-sum of 16 cavities which are fed by one common klystron. Two systems are in the test phase, with the goal to compare the performance of analog versus digital feedback systems [8]. With both systems, a field regulation has been obtained which meets the specification for module #1 (a few tenths of a degree in phase and a few 10^{-3} in amplitude under high gradient operation).

Beam Lines and Monitors

Many of the components of the above described beam line are installed. The complete installation will be accomplished together with the end of the injector installation, i.e. this fall. All components have been vacuum fired and carefully cleaned. Thus, the first few days of pumping showed encouraging results. The installed 50% of the beam line is very clean; the mass spectrometer shows almost only water. The expected pressure is in the order of 10^{-10} mbar.

Future plans

The plans for the use of the TTF Linac to operate a VUV light source yielding a coherent, very bright beam of photons with wavelength tunable between 20 and 6 nm are well developed. The modification of the TTF Linac set up is under preparation; together with the installation of modules #2 and #3 the set up will be completed by all components needed for a proof of principle experiment. The FEL gun as well as the undulator - the most complicated parts of the experiment - are under construction. Further information can be found in [9].

Conclusion

The first stage of the TTF Linac will be finished at the beginning of next year. A first beam is expected for spring. Then the rest of the year 97 will be devoted to experiments with this beam, and to the preparation of the remaining modules and the high charge injector. A test set up for the FEL gun will be operated at DESY; the final tests for the TESLA gun will be accomplished at FERMILAB. Experiments on the free electron laser are scheduled for 1998.

For the longer term future, it is planned to increase the linac energy to 1 GeV, thus extending the linac length by optimized versions of TESLA components.

References

[1] The TESLA (TeV Energy Superconducting Linear Accelerator) 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.

[2] D.A. Edwards ed., "TESLA Test Facility Linac Design Report", DESY Print, TESLA Rep. 95-01.

[3] F.Alessandria et al., "Design, Manufacture and Test of the TESLA-TTF Cavity Cryostat", Cryogenic Engineering Conference, Columbus, Ohio, 1995.

[4] D. Giove et al., „A Microstrip Based Position System for the Alignment of the TTF Cryostat“, Proc. 1995, Particle Accelerator Conference, Dallas, USA, p. 2093.

[5] Several contributions to the 1996 FEL Conference, Rome, Italy.

[6] T.Garvey et al., "Status of the TTF Linac Injector", this conference.

[7] W.-D. Möller et al., "Measurements of TESLA Cavities for TTF", EPAC 96, Sitges, Spain.

[8] S.N. Simrock et al., Contributions to the EPAC 96, Sitges, Spain.

[9] J. Roßbach, "New Linac Based FEL Projects Using Bright Electron Beams", this conference.