THE TESLA TEST FACILITY LINAC – STATUS REPORT

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Abstract

The TESLA Test Facility Linac (TTFL) is used to develop, construct and test components for a proposed TeV scale linear e^+e^- collider. The 390 MeV linac, set up by an international collaboration at DESY, is going to test three standard acceleration modules, each consisting of eight superconducting acceleration cavities and one superconducting quadrupole magnet module. Last summer a first module was commissioned successfully. An average accelerating gradient of 15 MV/m was established with beam; the RF macro pulse length of 0.8 ms at constant amplitude and phase corresponds with the TTFL design. According to the expectations the cryogenic operation showed very low static losses of only 6 W per module at 1.8 K. Different subsystems, e.g. low level rf control and timing, were commissioned and used to produce a 130 MeV beam. Results of first experiments using new beam diagnostic equipment are given. The extension to three modules is scheduled for 1998. A planned Free-Electron Laser setup which will demonstrate the new self amplified spontaneous emission principle at short wavelengths of a few ten nanometer is described together with the necessary components.

1 INTRODUCTION

In 1992 an international collaboration [1] proposed the TESLA Test Facility (TTF). It is a test bed situated at DESY to prove that accelerating gradients above 15 MV/m are consistently obtainable, and that superconducting cavities proposed for a TeV scale linear e^+e^- collider can be assembled into a linac test string (TTFL) [2]. Details of the design of the test facility are documented in a conceptual design report [3].

The TTFL program includes operation of the accelerating modules, control of the low and high level rf systems, cryogenic measurements, and testing cool down and warm up procedures. A low bunch charge injector (Injector I) with full beam current is used to establish beam acceleration and stable operation of the accelerating modules, measure basic beam characteristics, such as energy spread, emittance, and bunch length. In the near future, a high bunch charge injector based on a laser-driven rf gun (Injector II) will be used to measure HOM losses, space charge and wake field effects.

A summary of TTFL operating parameters is shown in Tab. 1.

2 INJECTION

The TTFL injector has been commissioned and is in operation since early 1997. It consists of a 250 kV thermionic electron source, a subharmonic buncher cavity, a superconducting rf capture cavity, and a diagnostic section. A complete description has been given elsewhere [4]. The capture cavity is identical to the 9-cell TESLA accelerating structure. It increases the beam energy to 10 MeV. The buncher cavity together with the capture cavity bunches the beam to 1 mm rms before it is injected into the accelerating modules. The diagnostic section includes a dipole magnet for energy measurements, several view screens, beam position monitors and Faraday cups. Optical transition radiation generated at an aluminum foil is used to measure the single bunch transverse profile with an intensified camera as well as the longitudinal profile with a streak camera. The measurements of beam current, energy, energy spread, beam profile, emittance, and bunch length agree well with the nominal operating parameters listed in table 1. A detailed report on measurements on the beam characteristics is given in reference [5].

Table 1: TTFL operating parameters.

Parameter	**TTFL**	
Energy gain of one module	120 MeV	
RF Frequency	1.3 GHz	
Acc. Gradient	15 MV/m	
Q_0	$3{\cdot}10^9$	
Nb. of Acc. Modules	3	
ΔE/E (single bunch, rms)	$1{\cdot}10^{-3}$	
ΔE/E (bunch to bunch, rms)	$2{\cdot}10^{-3}$	
Bunch Length (rms)	1 mm	
Macro Pulse Length	800 μs	
Macro Pulse Current	8 mA	
Lattice β (typ.)	12 m max	
	Inj. I	Inj. II
Injection Energy	10 MeV	20 MeV
Emittances, norm. (x,y)	5 mm mr	20 mm mr
Bunch Frequency	217 MHz	1 MHz
Particles per Bunch	$2.3{\cdot}10^8$	$5{\cdot}10^{10}$
Bunch Current	5 A	1 kA

It is planned to upgrade the injector with a laser-driven rf gun (Injector II) in order to generate a beam with characteristics close the beam proposed for the TESLA linear collider [6]. Injector II will also serve to generate a beam with very low emittances to drive the proposed free electron laser (TTF FEL) [7]. A detailed description of the Injector II project is given in [8].

3 ACCELERATING MODULES

Each accelerating module contains eight 9-cell superconducting niobium cavities and a quadrupole package. Each cavity has an rf power input coupler, two higher order mode output couplers, an rf pick up, and a mechanism to tune the frequency. They are operated at 2 K. The quadrupole package, operated at 4 K, consists of a superconducting quadrupole doublet, a beam position monitor, transverse steerers, and an additional higher order mode absorber.

In early summer 1997 the first module has been assembled and commissioned successfully and has been operated since then. An average gradient of 15 MV/m has been established with beam. An rf pulse length of 800 μs could be achieved with the design amplitude and phase stability. According to the expectations, the cryogenic operation showed very low static losses of only 6 W per module at 1.8 K. Different subsystems, e.g. low level rf control and timing, were commissioned and used to produce a 130 MeV beam. For instance the rf control feedback system based on Digital Signal Processors showed an excellent performance. The amplitude and phase stability during the 800 μs rf pulse using the feedback system is better than 0.5 % and 0.1° resp. [9], with an additional feed forward compensation the stability improves by a factor of 10 (Fig. 1).

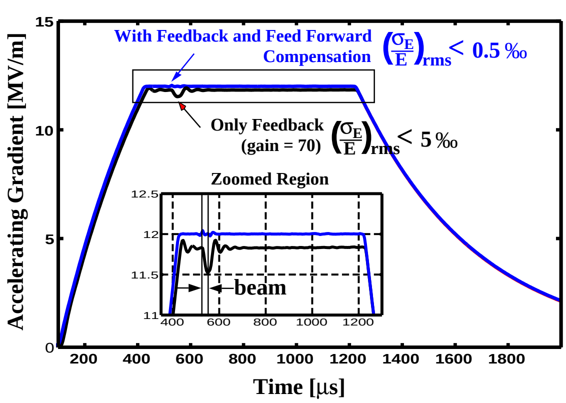

Figure 1: The accelerating gradient in a cavity as function of time during an rf pulse. The zoomed region shows the stability of the amplitude.

A system based on stretched wires with micro strip readout [10] is used to measure cavity movements during the cool-down and warm-up procedure. With a resolution of 10 μm it is able to verify alignment tolerances and reproducibility during thermal cycles. The measured cavity movements were found to be within the required tolerances of 0.5 mm.

4 CAVITY PROCESSING AND TESTING

The facility is equipped with a fully operational infrastructure to process and test cavities. It includes a complex of clean rooms, an ultra clean water plant, a chemical etching facility, and an ultra-high vacuum furnace. At present, 31 superconducting cavities from four european manufacturers have been processed and tested [11], more cavities for further modules have been ordered. Cavities are tested first in a vertical test stand in cw-mode, in order to have a quick check of their performance. After being welded into the helium tank, equipped with a motorized tuning system, the rf power coupler and the higher order mode couplers assembled, the last test prior to the assembly into a module is performed in a horizontal test stand. The cavity performance in the horizontal test stand in pulsed mode is comparable with the results of the vertical tests [12], and with their performance in the module.

The cavity processing and testing revealed two major reasons of the performance limitation. Some cavities showed very good performances in most cells, but had one cell with a quench at very low gradients. This behavior could be traced down to inclusions of foreign materials close to the inner niobium surface. Scanning the niobium sheets with the eddy current method prior to the cavity fabrication is now a standard procedure at TTF and detects inclusions of at least 200 μm in diameter up to a depth of 500 μm[13]. One series of cavities from a single manufacturer showed a continuously decreasing quality factor for gradients above 3 MV/m and quenches between 10 and 15 MV/m in all cells. With a temperature mapping system all quenches could be identified and originate from the equator welds. Optimization of welding parameters and welding under very clean conditions significantly improved the performance, a test cavity from the same manufacturer reached 25 MV/m without a quality factor degradation [14].

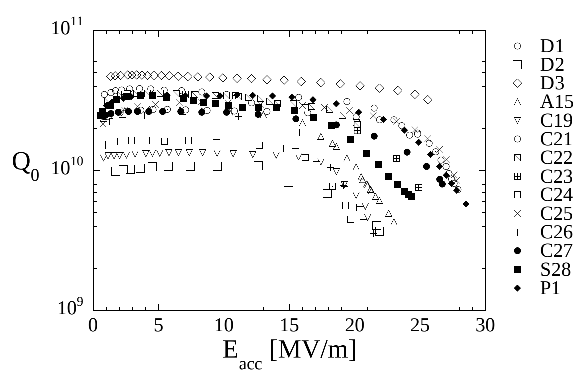

Figure 2: The quality factor as a function of accelerating gradient of those cavities measured in the vertical test stand, which reached more than 20 MV/m. The gradient of 5 cavities is limited by a quench in one cell, cavities C21, C22, C25, and S28 are limited by the available rf power.

A summary of the performance of cavities tested so far which have reached a gradient of more than 20 MV/m is shown in Fig. 2. It demonstrates, that the technique of processing and operating superconducting cavities above 20 MV/m is established.

5 RESULTS ON BEAM PARAMETER MEASUREMENTS

After acceleration, the beam passes an experimental area to measure all relevant beam parameters such as beam current, energy, energy spread, emittance, and bunch length.

The beam current and the transmission through the linac is measured by several toroids. The toroid system is able to detect beam losses of 10^{-3}. A beam with pulse length of 400 μs and a current of 5 mA could be transported with a transmission of 100 % through the whole linac. The energy measured with a dipole magnet was 130 MeV and thus confirmed the measurement of the gradient in individual cavities. Operation of the module at an average gradient of 15 MV/m has been established.

A powerful method for beam diagnostics is the use of transition radiation emitted from a thin aluminum foil being hit by the beam. The bunch length was measured using the coherent part of the transition radiation spectrum with a Martin-Puplett interferometer [15]. From the measured interferogram a bunch length of 1.5 ± 0.5 ps was deduced.

Two other methods to measure bunch lengths have been tested: gating of a Josephson junction with transition radiation in the THz range [16] and measuring the frequency spectrum of the transition radiation in the optical range [17].

All three methods have the advantage in respect to conventional streak cameras that they are able to measure as well much smaller bunch lengths in the 100 fs as planned for the TTF FEL project.

6 OUTLOOK

It is planned to install two more accelerating modules this year. The aim is to reach an average gradient of 20 MV/m with module 2 and 25 MV/m with module 3. It is also foreseen to upgrade the injector with an rf gun for high bunch charge (8 nC). This will allow further experiments concerning space charge and wake-field effects, and on higher order modes excited by the beam.

Furtheron, in early 1999 an undulator will be installed to perform a proof-of-principle experiment for the proposed TTF FEL [18]. This is a free electron laser based on self amplified spontaneous emission in the VUV region.

In addition, an experiment to recirculate a part of the FEL laser radiation into the undulator to build-up a regenerative amplifier is planned. This amplifier would lead to fully coherent VUV laser radiation with a narrow frequency band [19].

7 REFERENCES

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