THE RF-GUN BASED INJECTOR FOR THE TESLA TEST FACILITY LINAC

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Abstract

The TESLA Test Facility Linac (TTFL) at DESY is in the commissioning phase. During 1997 a first accelerator module was tested successfully. Eight superconducting cavities have accelerated the beam to an energy of more than 120 MeV. The injected 10 MeV electron beam was produced by a subharmonic injector using a thermionic gun, a buncher cavity, and one standard superconducting acceleration cavity. Since the achieved single bunch charge is not as high as needed for a TESLA Linear Collider, a laser driven RF gun is required. At present, two similar guns are under construction at Fermilab and DESY. The first one will produce 8 nC bunches with almost the TESLA time structure, i.e. 1 MHz repetition rate in 0.8 ms long bunch trains. This allows beam dynamics experiments in the TTFL. The second gun being developed at DESY will produce a very small emittance of normalized $2{\cdot}10^{-6}$ m rad at a reduced single bunch charge of 1 nC. The length of the bunch train will be 0.8 ms as well, the repetition rate can be increased to 9 MHz. This RF gun is needed to drive the planned DESY Free Electron Laser experiment. An overview about the installation is given and results of first experiments are described.

1 INTRODUCTION

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

A low bunch charge injector (Injector I) with full beam current of 8 mA and full pulse length of 800 μs is used to establish beam acceleration and stable operation of the acceleration modules, and to measure basic beam characteristics [4]. In the near future, the injector will be upgraded with a laser-driven rf gun to generate a high bunch charge of 8 nC running at 1 MHz (Injector II) [5]. This is necessary to perform various experiments at the TTFL concerning higher order mode losses, space charge and wake field effects. A schematic view of Injector II is shown in Fig. 1. The section between the capture cavity and the first accelerating module has already been modified. New vacuum components for the bunch compressor section, quadrupoles, steerers and view screens have been installed end 1997 and are in operation since then.

2 OVERVIEW

The electron source is a laser-driven 1 1/2-cell rf gun operating at 1.3 GHz [6] using a Cs_2Te cathode. A load lock cathode system allows to change cathodes while maintaining ultra-high vacuum conditions. The cathode is illuminated by a train of UV laser pulses. A second rf gun with a different design [7] is being tested in a test beam line at TTF. This gun is optimized for very low emittances to drive the proposed Free Electron Laser (TTF-FEL) [8].

The gun section is followed by a superconducting rf capture cavity, and a bunch compressor. The capture cavity is identical to the 9-cell TESLA accelerating structure. It increases the beam energy to 20 MeV. The bunch compressor is a magnetic chicane to compress the bunch to σ_z = 1 mm. Several diagnostic methods are applied: a dispersive section for energy measurements, several view screens, beam position monitors, and Faraday cups. Transition radiation generated at an aluminum foil is used to measure the transverse bunch profile and the bunch length. Slit masks are used to measure the transverse emittance. The last section is dedicated to experiments to excite and measure higher-order modes in the accelerating structures. Table 1 gives a summary of the injector operating parameters.

Table 1: Injector II operating parameters for TTFL and TTF-FEL operation.

Parameter		TTFL	FEL
Frequency	GHz	1.3	
Rep. Rate	Hz	10	
Macro Pulse Length	μs	800	
Bunch Frequency	MHz	1	9
Bunch Length (rms)	mm	1	0.8
Bunch Charge	nC	8	1
Bunch Current	kA	1	0.1
Emittance, norm. (x,y)	mm mr	20	2
ΔE/E (single bunch, rms)		$1{\cdot}10^{-3}$	
ΔE/E (bunch to bunch, rms)		$2{\cdot}10^{-3}$	
Injection Energy	MeV	20	

3 THE RF GUNS

Both rf guns are 1 1/2 cell TM_{010} π-mode structures operated at 1.3 GHz. They are based on a design reported in [9]. To achieve a good beam quality at high bunch charges, the gun is operated at high rf accelerating gradients. At present, a 5 MW Klystron is available which allows an accelerating field of up to 50 MV/m. The rf induced emittance growth is minimized by optimizing the geometrical dimensions of

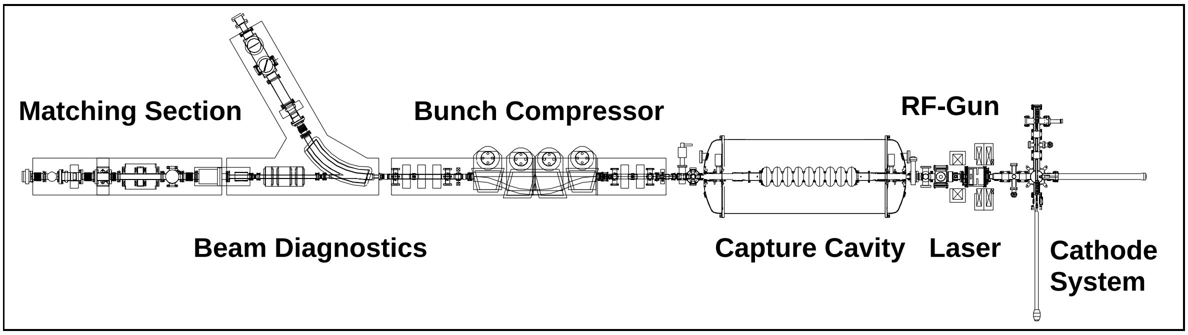

Figure 1: Schematic view of Injector II.

the gun. To reduce the correlated space charge induced emittance growth [10] solenoid fields give the required focussing kick. The half cell length is chosen to be slightly longer than $\lambda/4$ to improve the transverse emittance.

The rf gun for TTF high charge operation couples the RF from the side via a rectangular waveguide through a slit into the full cell. The rf gun optimized for low emittances uses a coaxial coupling [7]. In this case, the symmetry is not disturbed, asymmetric modes are strongly suppressed. Dipole modes, which can be generated in the door-knob transition are damped in the coaxial line. Further on, the position of the focussing solenoid can be optimized freely. A summary of rf gun operating parameters is shown in Tab. 2.

Table 2: RF gun operating parameters for the TTF high charge gun and the FEL low emittance gun.

Parameter		TTFL	FEL
Frequency	GHz	1.3	1.3
Nb. of cells		1 1/2	1 1/2
RF coupling		transverse	coaxial
Ave. Gradient	MV/m	35	50
Klystron Power	MW	2.3	4.5
Av. Diss. Power	kW	22	45
Rep. Rate	Hz	10	10
RF Pulse Length	μs	800	800
Nb. Bunches/Pulse		800	7200
Bunch Spacing	ns	1000	110
Bunch Charge	nC	8	1
Peak Current	A	500	125
Emitt., norm. (x,y)	mm mr	15	1
Emitt., norm. (z)	keV mm	40	20

4 THE CATHODE SYSTEM

The cathode material chosen is Cs_2Te because of its high quantum efficiency of more than 1 % over a reasonable operating time of 1000 h [11]. This type of cathode has to be illuminated by UV laser light with a photon energy above 4.5 eV, its response to short laser pulses is less than 2 ps [12]. Its lifetime depends strongly on the vacuum quality, namely the partial pressure of oxygen, CO_2, water, and hydrocarbons. It has to be kept below $1\cdot10^{-11}$ mbar [13]. Therefore, the cathode system allows changing cathodes while maintaining ultra-high vacuum condition.

The cathode system has 3 major parts: The preparation chamber to prepare cathodes, a transport chamber to transport fresh cathodes to the loading system connected to the rf gun. The loading system has manipulators to take cathodes from the transport chamber and to insert them into the gun.

A prototype system has been successfully tested, a second system has been built and is now installed in the TTF rf gun test beam line. Cathodes with a quantum yield of over 10 % have been prepared. In the rf gun environment, the yield was kept stable at 1 % [14].

5 THE LASER SYSTEM

Two laser systems have been developed: one for the A0 Test Facility at Fermilab (Univ. of Rochester) [15], and one for TTFL at DESY (Max-Born Inst., Berlin) [16]. The laser illuminates the photo cathode with ps UV laser pulses. A bunch charge of 8 nC requires 5 μJ of UV laser energy only (1 % quantum yield). However, the unusual long TTFL bunch train length of 800 μs with 800 bunches per train at 10 Hz repetition rate is a challenge for the laser design.

Different approaches have been chosen. The A0 laser system uses a mode-locked Nd:YLF solid state laser system (λ = 1054 nm) to seed a series of multi-pass amplifiers. A flash lamp pumped Nd:glass slab amplifier performs the final energy amplification to 1 mJ per single pulse. After pulse compression to 10 ps, the 4th harmonic (263 nm) is generated with an efficiency of 10 % in two non-linear crystals (BBO).

The DESY system is based entirely on flash lamp pumped Nd:YLF (λ = 1047 nm). This material has a long fluorescence lifetime, high induced emission cross section, and very small thermal lensing. The system uses a Pulse Train Oscillator (PTO) to generate a 4 ms long pulse train. The PTO is a pulsed mode-locked oscillator locked to a harmonic (54 MHz) of the TTF master rf oscillator. It is controlled by a phase and amplitude feedback system. A phase stability of better than 1 ps and a pulse to pulse energy stability of better than 1 % is achieved. The 54 MHz bunch train is reduced to 1 MHz with a length of 800 μs by a Pockels-cell pulse picker. For the TTF-FEL 9 MHz operation is foreseen. This train is amplified by three single pass amplifiers to 250 μJ per single pulse. The UV (262 nm) generation with two nonlinear crystals has an efficiency of 10 %. A feed-forward system is applied to preset the shape of the flash lamp current pulse to obtain a flat pulse train. The feed-forward table is updated using the UV output on a shot-to-shot basis. The UV pulse to pulse energy variation obtained over the whole train is better than 5 %, the pulse length is estimated to be 12 ps (FWHM).

6 DIAGNOSTICS

A large variety of diagnostic methods are used. A set of integrated current transformers measure the beam current. Button type pick-up beam position monitors are installed to control the beam up- and downstreams of the bunch compressor chicane. Three Faraday-cups are used to measure the bunch charge. The dispersive section is equipped with a view screen and an SEM grid. Five of the seven diagnostic stations have motorized actuators and can hold a package of diagnostic screens: a view screen, an aluminum foil for transition radiation, a mask composed of slits, and a calibration plate. The transverse emittance is measured using slit or pepper pot masks. The bunch length is measured using coherent transition radiation from the foils with an interferometer [17].

7 FIRST RESULTS AND OUTLOOK

The commissioning of the rf gun prototype was successfully finished in 1996 at the Argonne Wakefield Accelerator, followed by continued testing of the principle scheme of Injector II at the Fermilab A0 Test Facility. First measurements were performed with prototype equipment. The rf gun was operated under ultra-high vacuum conditions with a Cs_2Te cathode. Gun conditioning to rf pulse length up to 400 μs at 3.5 MW has been completed [14]. Water-turbulences induced wall vibrations did not induce measurable phase shifts of the gun cavity. A considerable dark current in the order of mA was measured. The dark current originates mainly from the rf contact spring centering the cathode. Alternatives of the spring design are being tested in the next run.

Two new rf guns are now being built at Fermilab, one is now being tested in the A0 test facility. In parallel, the TTF-FEL rf gun is installed in the test beam line at DESY.

It is planned to install one rf gun into the TTFL Injector later this summer. In 1999, the low emittance gun will be used to perform the proof-of-principle experiment for the proposed TTF-FEL [18].

8 REFERENCES

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