PERFORMANCE STATUS OF THE RF-GUN BASED INJECTOR OF THE TESLA TEST FACILITY LINAC

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Abstract

The TESLA Test Facility Linac (TTFL) at DESY uses two modules with 8 TESLA superconducting accelerating structures each to accelerate an electron beam up to 360 MeV. At present, the beam has been used to perform the proof-of-principle test of the TTF Free Electron Laser and to continue various experiments for the TESLA linear collider project. For this, an rf-gun based photoinjector was installed late 1998 and is in operation since then. It produces a 0.8 ms long train of 1 nC or optionally 8 nC bunches spaced by 1 μs with low transverse emittance. The performance of the injector during the last run from July 1999 to end of April 2000 is reported.

1 INTRODUCTION

The TESLA Test Facility (TTF) at DESY built by an international collaboration [1] is a test bed to prove that superconducting cavities as 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]. During the initial running periods in 1997 and 1998, a low bunch charge injector with full beam current of 8 mA and full bunch train length of 800 μs has been used to establish beam acceleration and stable operation of a TESLA acceleration module [3]. In 1998, the injector has been upgraded with a laser-driven rf gun [4] to match the beam charcteristics as close as possible to the TESLA proposal. It is able to generate high bunch charges of 8 nC with 1 MHz repetition rate within a train of 800 μs in length; 2.25 MHz for 4 nC bunches is in preparation. It is used to perform various experiments concerning higher order mode losses, space charge, and wake field effects. It also serves as an injector to drive the TTF-FEL free electron laser [5].

2 OVERVIEW

A schematic overview of the TTF injector is shown in Fig. 1, further details can be found in [6]. The electron source is a laser-driven L-band rf gun using a Cs_2Te cathode. The cathode is illuminated by a train of UV laser pulses generated in a mode-locked solid-state laser system synchronized with the gun rf. The gun section is followed by a superconducting capture cavity, a bunch compressor, and an energy spectrometer. The capture cavity is identical to a 9-cell TESLA accelerating structure. It boosts the beam energy up to 20 MeV. The design parameters of the injector are listed in Table 1 for TESLA related experiments and TTF-FEL operation.

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Table 1: Injector design parameters for TESLA related experiments (TTFL) and TTF-FEL operation.

Parameter		**TTFL**		**FEL**
		(a)	(b)	
RF frequency	GHz	1.3		
Rep. rate	Hz	10		
Pulse train length	μs	800		
Pulse train current	mA	8	9	9
Bunch frequency	MHz	1	2.25	9
Bunch charge	nC	8	4	1
Bunch length (rms)	mm	1	1	0.8
Emitt. norm. (x,y)	μm	20	10	2
ΔE/E (rms)	%	0.1		
Injection energy	MeV	20		

3 THE RF GUN

The rf gun is a 1 1/2 cell TM_{010} π-mode structure operated at 1.3 GHz. In the last run from July 1999 to April 2000 it has been operated with a gradient on the cathode of 37 MV/m and an rf pulse length of 100 μs at 1 Hz. During the next run starting in summer 2000, the rf pulse length will be extended to 800 μs at 5 Hz. This has already been achieved at the A0 Test Facility at FNAL, where the gun has been built and tested in the framework of the TESLA collaboration [7]. At A0, a second identical gun is being operated now. At DESY, a low emittance gun dedicated to FEL operation is in development [8]. The focussing kick from a pair of solenoids is used to compensate for space charge induced emittance growth [9]. A low level rf control system has been developed to stabilize amplitude and phase during the rf pulse. A system based on digital signal processors similar to the system used for the accelerating modules is used [10]. A summary of the rf gun design and typical operating parameters is shown in Table 2.

In general, the rf gun runs very stable and reliable. An exception was the onset of strong emission of electrons in February this year from an emitter in the first half cell. One week was lost for reconditioning. Since then, the gun is running smooth again at nominal gradient.

4 THE CATHODE SYSTEM

To operate with 800 high charge bunches per train, a cathode with a quantum efficiency in the percent range has to be choosen in order to make the required laser effordable. The Cs_2Te cathode has a high quantum efficiency between 0.5 % and 6 % and withstands the extraction of high peak currents bunches. For a current of 8 mA per bunch train,

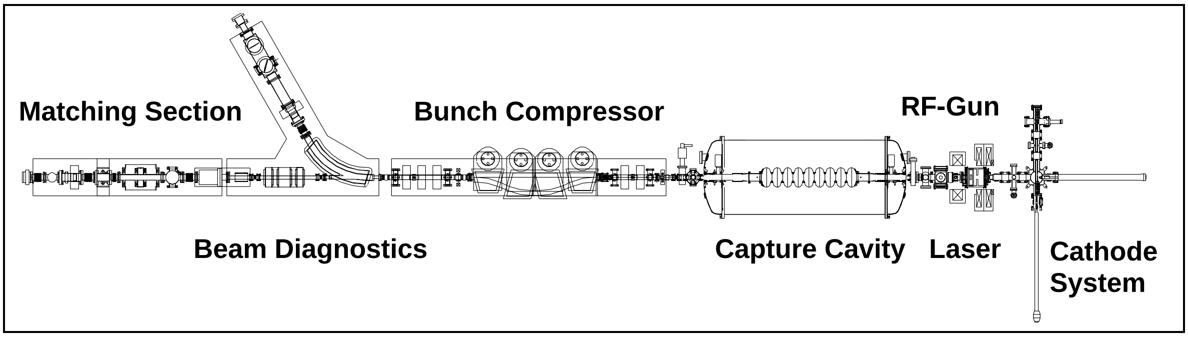

Figure 1: Schematic overview of the TTF injector. Beam direction is from right to left; the laser system is not shown.

Table 2: RF gun design parameters compared to typical operating values during the last runs.

Parameter		Design	Operated at
Gradient at cath.	MV/m	35	35 . . . 44
Rep. rate	Hz	10	1 . . . 10
RF pulse length	μs	800	50 . . . 800
Bunch charge	nC	8	1 . . . 8
Bunch spacing	μs	1	1
Bunch length (rms)	mm	2	2 . . . 4
Emitt. norm. (x,y)	μm	2	3 . . . 5
Energy spread (rms)	%	0.1	0.13

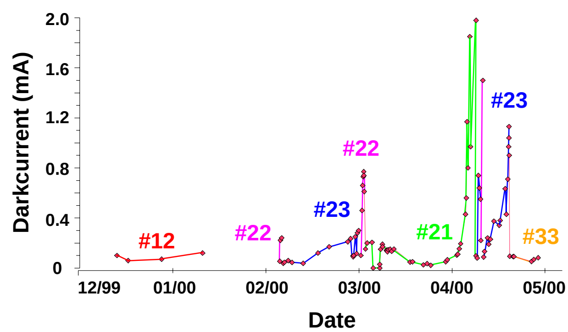

Figure 2: Darkcurrent history of this year, measured at the rf gun exit. Number of cathode in use is indicated.

5 W of UV laser power per train is required. This can be achieved by a laser system with a reasonable overall average power of 1 to 2 W.

The achievable quantum efficiency depends strongly on the vacuum quality, namely impurities like oxygen, CO_2, water, and hydrocarbons. Their partial pressure has to be kept below $1{\cdot}10^{-11}$ mbar [11]. A load-lock system has been developed allowing insertion and replacement of cathodes while maintaining ultra-high vacuum conditions.[12] However, the vacuum condition in an rf gun during operation cannot be as good as in the cathode system itself. The pressure measured at ion getter pumps close to the gun during operation is below $1{\cdot}10^{-10}$ mbar, but the pressure at the cathode is probable higher. Therfore, the cathodes show their high quantum efficiency (6 %) only at start-up. It stabilizes in a few days to 0.5 %.

From Dec. 1998 to April 2000, seven different cathodes have been operated in the rf gun. None of the cathodes has been changed because of low efficiency, but due to large darkcurrent. The darkcurrent measured at the gun exit with a Faraday cup is initially below 20 μA. However, for most cathodes we observed a fast rise in darkcurrent to mA after some days or weeks. Figure 2 shows the darkcurrent history of this year. The cathode in use is indicated with its number. Most of the darkcurrent is emitted from the region between the cathode and the rf gun backplane, where a Cu-Be spring is used to assure good rf contact. An investigation of the darkcurrent behavior and inspection of the backplane and rf contact spring did not lead to a conclusive understanding of the sudden rise. Two approaches seam to cure the problem at least for short terms: retracting the cathode from the gun for some time to better pump the cathode region, and to change the cathode to a fresh one. With these measures, the darkcurrent could be kept below 200 μA with the expense of frequent run interruptions.

5 THE LASER SYSTEM

A description of the laser system is given in [13]. The laser is based on flashlamp pumped Nd:YLF rods lasing at 1047 nm. This material has a long fluorescence lifetime, high induced emission cross section, and very small thermal lensing, which is favorable for long pulse trains. A 2 ms long train of ps short pulses is generated in a mode-locked oscillator running at 54 MHz. An electro-optic modulator driven with 1.3 GHz locked to the TTFL master rf oscillator enhances the phase stability in respect to the gun klystron rf to less than 1 ps. A Pockels-cell based pulse picker divides by 54 to form a 1 MHz pulse train. The train length is adjustable. A 2.25 MHz pulse picker has been installed and will be used in the next run. A operation at 9 MHz is foreseen in a later stage.

The train is amplified by three single pass amplifiers to 250 μJ per single pulse, thus 200 mJ per train. Running at 10 Hz, an average laser beam power of 2 W is achieved. The UV wavelength (262 nm) is generated with two nonlinear crystals with an efficiency of 15 to 20 %. An energy stability in the UV of $\pm 5\,\%$ (rms) is achieved. The laser pulse length at 1047 nm (IR) is measured with an autocorrelation method and after conversion to the UV with a streak camera [14]: $\sigma_t^{\rm IR} = 9.8 \pm 0.8$ ps, $\sigma_t^{\rm UV} = 7.1 \pm 0.6$ ps.

During the last run with 4896 h of continuous operation at 1 Hz, the laser had an up-time of 89 % corresponding to $1.6 \cdot 10^7$ shots.

6 PERFORMANCE STATUS

Measuring the charge at the gun exit e.g. as a function of the relative phase of the gun rf with the laser pulse gives information about the phase acceptance, the laser pulse length, space charge and other effects (Fig. 3a). From the rising edge, the laser pulse length can be estimated. Figure 3b shows the reconstructed laser pulse shape. For this, the charge densities should be small to avoid a lengthening of the rising edge due to space charge effects. At low cathode quantum efficiency (0.5 %), the flat top shows a slight increase in charge with phase. This is explained by the decrease of the workfunction due to the increasing rf field gradient on the cathode for higher phases (Schottky effect).

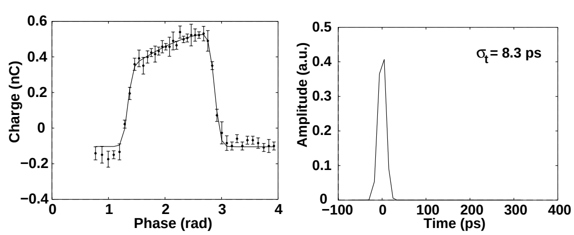

Figure 3: Charge measured at the gun exit as a function of the relative phase gun/laser (left) and the reconstructed laser pulse length from the rising edge (right).

The beam energy has been measured with and without the capture cavity, the results are in agreement with the expectation from the accelerating gradients: 3.8 ± 0.1 MeV for 35 MV/m (gun only) and 16.5 ± 0.1 MeV with a capture cavity gradient of 12 MV/m. The energy spread has been determined by imaging the beam in the spectrometer beamline using optical transition radiation (OTR) on a thin aluminum foil. The gaussian core of the energy distribution gives 22.1 ± 2.7 keV, corresponding to $0.13 \pm 0.02\,\%$ rms energy spread. The distribution has a 50 keV tail.

The electron bunch length has been measured with a streak camera as a function of rf gun phase. The bunch lengths vary between $\sigma_z = 2$ mm for low phases and 5 mm for 60°. The phase dependence of the bunch length is in good agreement with simulations assuming a laser pulse length of 14 ps. This is longer than expected by the laser pulse length measurements.

For a bunch charge of 1 nC, the emittance has been frequently determined at two locations in the injector. The transverse beam profile at an OTR view screen is measured as a function of quadrupole currents. In addition, a slit mask system is used. The emittance has been measured for various settings of the two solenoids. At the current working point, a normalized emittance of $4 \pm 1\,\mu$m rad is achieved.

7 CONCLUSION

The last running period from summer 1999 to spring 2000 has been a success. The injector provided beam close to the design performance. However, sudden rapid rise in dark-current emitted from the gun forced a frequent change of cathodes.

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[14] The streak camera (ARP, Kehl, Germany) was made available to us by LAL, Orsay (France).