HIGH POWER RF CONDITIONING AND MEASUREMENT OF LONGITUDINAL EMITTANCE AT PITZ

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Abstract

In 2003 the PITZ rf gun at Zeuthen has been completely characterized. After the rf conditioning, 3.0 MW peak input power at 10 Hz and a rf pulse length of 0.9 ms have been reached. This corresponds to a gradient of 42 MV/m at the cathode. The goal is to increase the accelerating gradient of the gun and the duty cycle significantly. The motivation is based on the expectation of a remarkably increase in beam quality at higher gradients. A high duty cycle is of advantage for FEL users. The conditioning procedure of a new gun cavity was started in spring 2004. The paper will report about procedure and results of the conditioning. The preparation of an experimental setup for the measurement of the complete longitudinal phase space at about 5 MeV using a streak camera will be finished in summer 2004. Cherenkov light created by Silica aerogel radiators in the dispersive arm of PITZ is transmitted to a streak camera by an optical transmission line. The light distribution of the momentum spectrum is projected onto the entrance slit of the streak camera. The setup will be presented.

INTRODUCTION

The photo injector PITZ at Zeuthen [1] is a dedicated facility for the investigation of rf guns for FELs, i.e. the VUV-FEL and the European XFEL and future linear colliders. The experimental setup consists of a 1.5 cell L-band rf gun with a Cesium-Telluride photo-cathode. A solenoid system is used for space charge compensation. The photocathode laser is capable to generate pulse trains up to 0.8 ms length with a pulse to pulse separation of 1 µs. An extended diagnostics section is used for the experimental investigation of the produced electron beam. The first stage of the PITZ project (PITZ1) was successfully finished in fall 2003 with the complete characterization of the rf gun [2] which was then transferred to the VUV-FEL project of DESY in Hamburg. A schematic of the PITZ1 setup is shown in Fig.1.

In spring 2004 another rf gun was installed at PITZ and a dedicated program of rf conditioning was started. The goals of this high power conditioning are essentially the following:

- maximize the gradient at the cathode
- increase the duty cycle

The maximization of the gradient is aimed to optimize the beam quality, especially for minimization of the transverse emittance. The increase of the duty cycle is useful for the user community of the future FELs. The results of the conditioning program are outlined in the next chapter.

The preparation of the longitudinal emittance measurement is described in the third chapter. The aim is the measurement of momentum spread and bunch length as well as the correlation between them. The principle of the measurement will be outlined with emphasis on optical problems of light collection and imaging.

HIGH POWER RF CONDITIONING OF THE PITZ GUN

Status reached in 2003

The results of the rf conditioning of the rf gun in 2003 are shown in Table 1.

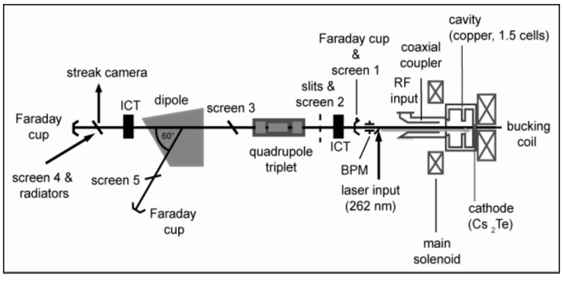

Figure 1: Scheme of the PITZ setup

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Table 1: Results of rf conditioning of the gun achieved in 2003

repetition rate	10 Hz
rf pulse length	0.9 ms
peak power at gun	3 MW
gradient at cathode	42 MV/m
mean power	27 kW
duty cycle	0.9%
maximum momentum	4.7 MeV/c

Program for gun conditioning

A longer term program for the conditioning of rf guns at PITZ was set up, which considers also the availability of a high power klystron and further hardware conditions.

This program consists of four steps:

1) Conditioning up to the status reached for the gun operated in 2003
2) Conditioning to the maximum reachable peak power, rf pulse length, mean power and duty cycle using the currently available 5 MW klystron
3) Replace the 5 MW klystron by a 10 MW klystron, perform conditioning to the maximum reachable parameters of peak power, mean power and duty cycle
4) After performing R&D on the rf system increase the repetition rate (and such the duty cycle and mean power) in a first step to 50 Hz repetition rate for a future RF gun

Status of conditioning using a 5 MW klystron

Concerning most of the essential parameters of last year [3] the status of conditioning was again reached in spring 2004. After that, a dedicated conditioning with three parameter sets was performed. The goals were the maximization of the rf peak power using the 5 MW klystron, the maximization of the rf pulse length, the maximization of the mean rf power and of the duty cycle for the given hardware conditions. The three parameters sets are characterized by a repetition rate of 10 Hz and a length of the rf pulse of 0.5 ms for the first set, by 5 Hz repetition rate and 1.3 ms pulse length for the second set and 10 Hz and 1.0 ms for the third set. The results are shown in Table 2. The high energy edge of the dark current spectrum for a 0.5 ms rf pulse is shown in Fig.2.

Table 2: Results of rf conditioning in 2004

Repetition rate	10 Hz	5Hz	10 Hz
rf pulse length	0.5 ms	1.3 ms	1.0 ms
peak power at gun	4 MW	4 MW	3 MW
mean power	20 kW	26 kW	30 kW
duty cycle	0.5%	0.65 %	1%
maximum momentum	5.17 MeV/c	5.17 MeV/c	–

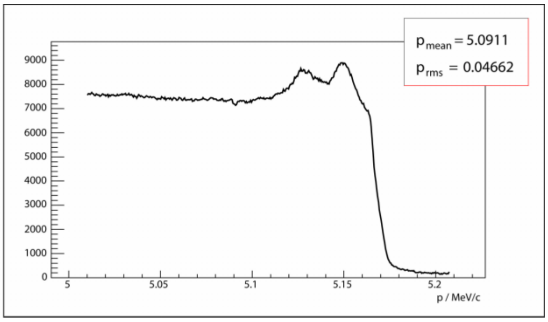

Figure 2: High energy part of dark current spectrum for the parameter set with 0.5 ms rf pulse

The maximum rf peak power, the mean power, the duty cycle and the beam momentum could already be increased compared to 2003. At present, the current water cooling system is a limitation for reaching higher mean power. At the end of 2004 the cooling system will be upgraded to higher cooling power. The program will be continued afterwards.

Dark current

The measured dark currents are about a factor 10 higher for this gun than for the former one. It is assumed that the reason for the higher dark currents is based on a limited copper surface quality of the present gun [4]. The dark current depending on the solenoid current is shown in Fig. 3 for an input power of 4 MW.

Outlook

The conditioning program will be continued. The next essential milestone will be the replacing of the 5-MW-klystron by a 10-MW-klystron in 2005. This will allow an essential increase of the peak power and mean power.

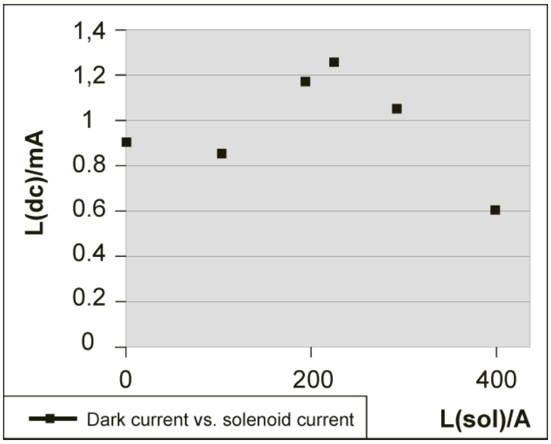

Figure 3: Dark current vs. current of main solenoid for 4 MW input power for the current PITZ gun (prototype #1)

MEASUREMENT OF THE LONGITUDINAL EMITTANCE AT PITZ

The goal is the quasi-simultaneous measurement of momentum, momentum spread and bunch length as well as the correlation between the last two items.
The measurement of momentum and momentum spread will be performed in the usual way [5] in the magnetic spectrometer of PITZ. The measurement of the bunch length will be realized using a streak camera. The length of the electron bunches is measured by transforming the electron bunch in light pulses of same length. This is mainly done using Cherenkov effect, but Optical Transition Radiation (OTR) is also used for cross-check. At a beam energy of less than 5 MeV OTR is less suitable because of the low light output and the spatial emission characteristics which make it difficult to collect the light.
The streak camera to be used for the measurement is a synchroscan camera type C5680 from Hamamatsu [6] with a time resolution of about 2 ps.
The light created by the radiators (Cherenkov, OTR) [5] is transmitted by an Optical Transmission Line (OTL) to the streak camera. For PITZ the length of the OTL is 27 m which is a challenge for the design of the optical system.

Optical transmission line

A simplified schematic of the OTL is shown in Fig. 4:

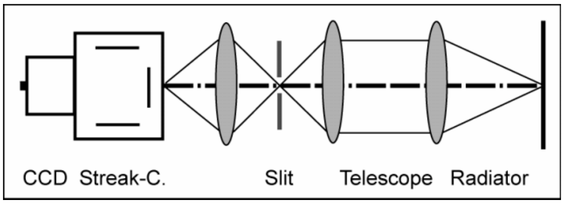

Figure 4: Schematic of an optical transmission line

The light is emitted by the radiator. It is collected by the first lens of the optical chain mainly consisting of several telescopes. The object light distribution is imaged onto the entrance slit of the streak camera. The light distribution in the slit plane is projected onto the photocathode of the streak camera by an internal optical system.

Most of the time during data taking, the streak camera at PITZ is also used for the measurement of the length of the photocathode laser pulse and the corresponding optimization of the temporal profile. The laser emits light in the UV region, therefore the internal optics should have transmission for 262 nm. System 1 in Table 3 is suitable for these conditions but has a small aperture. For measurements of light from radiators a high aperture of the internal lens is needed in some cases. This is realized with system 2 which has the largest aperture, but is not suitable for the measurement of the laser pulse length in the UV region. Furthermore the internal lens should not contribute to the time dispersion. System 3 in Table 3 fulfills these demands but has a rather small aperture. Therefore three different internal optical systems are available at PITZ to match the different demands of the experiment properly.

Table 3: Properties of the internal optical systems of the streak camera

	Name	Spectr. Transmission/nm	Eff. F_{no}	Magnification
1	A 1976-01	200..1600	5.0	1
2	A 1974	400...900	1.2	1
3	A 6856 (mirror lens)	200...1600	4	1

There are several demands to the optical transmission line:

- project the image of the light distribution of the radiators onto the entrance slit of the streak camera
- assure, that the readout for the streak camera measurement is possible for screen 5 in the dispersive arm and for screen 4 in the straight section behind the dipole
- match the optical system of the OTL to different input optical systems

Two principle solutions of the optical input system directly behind the radiators are foreseen. The reason is the condition, that one cannot simultaneously image an extended object, for example the object light distribution of the beam momentum spectrum with a width of about 40mm, with a high aperture by a chain of lenses. Therefore we have foreseen two input optical systems, one for high aperture and small object extension using the full Cherenkov cone (“full cone”), the second for imaging the full momentum spectrum with small aperture, i.e. with a small angular section of the Cherenkov cone. Basing on these design considerations and further design principles [7] the OTL was designed. The schematic of the full OTL is shown in Fig. 5.

It includes two branches for the dispersive arm (measurement of the longitudinal emittance) and two branches for measurements at screen 4.

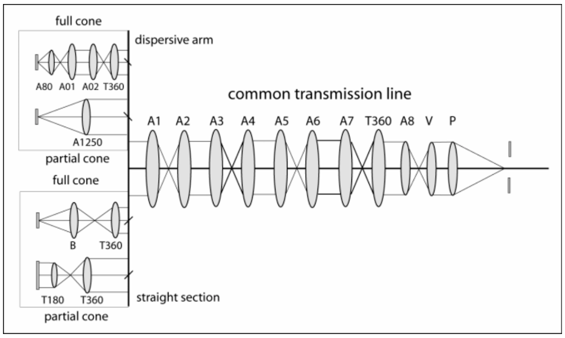

Figure 5: Schematic of the optical transmission line, the abbreviations are presented in Table 4

Table 4: Explanation of abbreviations in Figure 5

Achromats		Photo lenses	
name	focal length/mm	name	data
A80	80	B	Biotar 1.5/75mm
A01, A02	500	V	Visionar 1.6/71mm
A1, A2, A3, A6	2250	P	Pancolar 1.8/50m
A4, A5, A1250	1250	T180	Tessar 4.5/180mm
A7	800	T360	Tessar 4.5/380mm
A8	160	–	———

Special subsystems

Two special subsystems are included in the OTL:

- the Image Rotating System (IRS)
- the Image Turning Box (ITB)

The Image Rotating System is used to rotate the image such that the azimutal direction of the image light distribution of the momentum spectrum matches to the horizontal orientation of the entrance slit of the streak camera. This is needed because the axis of the dispersive arm has an inclination of 60 degrees and consequently the orientation of the light distribution of the momentum spectrum too. The Image Turning Box is used to check whether the Image Rotating System introduces unwanted contributions to fractions of the image distribution in the light propagation direction. The Image Turning Box turns the image by 180 degrees. Measurements with and without the Image Turning Box allow to correct on such unwanted contributions. Besides these two systems, several diagnostics tools are foreseen, for example several illuminated objects which can be moved in a plane corresponding to the object plane. These objects can be used to adjust the OTL and find the low level light image distribution in front of the streak camera slit. The use of an illuminated slit object helps to prove the azimutal orientation of the image of the momentum spectrum light distribution. The elements are mounted in a box containing switchable optical components near to the optical port.

Time dispersion

The optical transmission line mainly consisting of large achromats causes a non-negligible time dispersion [8]. The main sources of the time dispersion are chromatic aberrations of the diffractive systems as could be demonstrated by the use of optical bandpass filters [5], see Fig. 6. For a small bandwidth the time dispersion is negligible. The use of the internal optical system of the streak camera consisting of reflective optics results in a decrease of the measured bunch length by 3 ps. A R&D project which aims in replacing refractive optics by reflective optics is ongoing.

Status of the project

The optical transmission line will be mounted and adjusted in September 2004. The first measurements with electron beam will start end of September 2004.

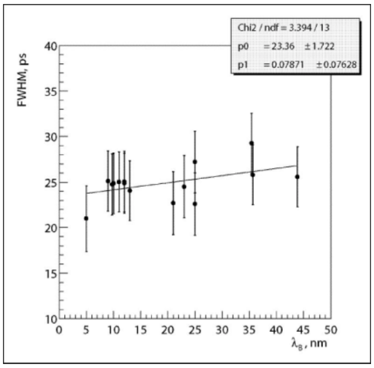

Fig. 6: Optical pulse length vs. filter bandwidth

OUTLOOK

Besides the conditioning program, the preparation of the longitudinal emittance measurement, and a complex measurement program for the characterization of the rf gun currently in use [9], an essential upgrade of PITZ, the PITZ2 project [10], is in preparation. The main goal is studying the principle of conserving small emittance to higher beam energy and further improving the emittance generated in the gun. A minimal version of PITZ2 will be commissioned in the beginning of 2005. The measurement of the longitudinal emittance is foreseen at PITZ2 in the low energy and high energy section at several ports basing on the principles explained in this paper.

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