PAUL SCHERRER INSTITUT

Design and Calibration of an Emittance Monitor for the PSI X-FEL Project

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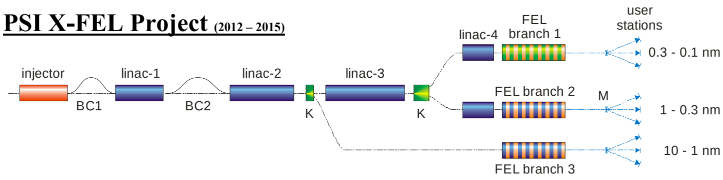
Abstract

The Paul Scherrer Institute (PSI) intends to realize a compact X-ray Free Electron Laser (XFEL) based on the development of a high brightness, high current electron source. Field emitter arrays (FEA) in combination with high gradient acceleration promise a substantial reduction of transverse emittances by up to one order of magnitude compared to existing electron sources for XFELs. The acceleration concept and the main beam parameters will be demonstrated in a 250 MeV injector LINAC project. A flexible, high resolution emittance meter based on the pepperpot measurement technique has thus been designed to characterize this low emittance beam. The realization of this monitor and the calibration procedure will be presented.

PSI X-FEL Project (2012 – 2015)



Main Accelerator Parameters

Beam Energy:	5.8	GeV
Bunch Charge:	200	pC
Peak Current:	1.5	kA
Bunch Length:	35	fs
Norm. Emittance (slice):	≤ 100	nmrad
Energy Spread (slice):	0.6	MeV
Rep.-Rate:	10 (100)	Hz

Main FEL and Facility Parameters

FEL Facility Length:	≤ 800	m
Radiation Wavelength:	1	Å
Photon Energy:	12.5	keV
Peak Power:	1	GW
Undulator Period:	15	mm
Undulator Type:	planar	
Undulator Strength:	K = 1.19	
Undulator Length:	≤ 30	m

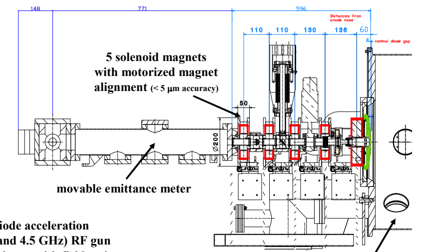
Phase-1 – FEL Gun Test Facility (2007 – 2010)

Beam Parameters

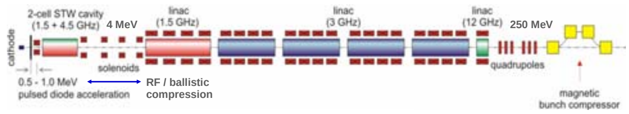
Beam Energies:	500	keV
	1	MeV
	4	MeV
Bunch Charges:	5 – 200	pC
Bunch Currents:	0.1 – 5.5	A
Bunch Length:	~ 35	ps
Norm. Emittance:	50 – 200	nmrad
Energy Spread:	0.5	eV
Rep.-Rate:	10 (100)	Hz

Project Goals

- demonstrate high gradient pulsed diode acceleration
- demonstrate 2 frequency (1.5 GHz and 4.5 GHz) RF gun
- demonstrate low emittance electron beam with field emitter arrays



Phase-2 – FEL Injector (2008 – 2012)

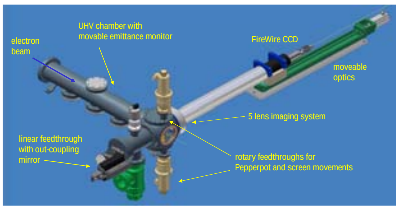


Main Accelerator Parameters – Project Goals

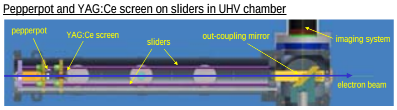
Beam Energy:	250	MeV
Bunch Charge:	200	pC
Norm. Emittance (slice):	≤ 50	nmrad
Energy Spread (slice):	0.6	MeV
Bunch Length:	≤ 400	fs
Peak Current:	360	A
Rep.-Rate:	10	Hz

- demonstrate ε conservation and ε preservation during acceleration
- demonstrate bunch compression through combination of RF / ballistic and magnetic compression
- demonstrate reliability of field emitter arrays and high gradient pulsed diode acceleration
- optimization of PSI X-FEL injector (re-used in XFEL project)

Movable Emittance Meter



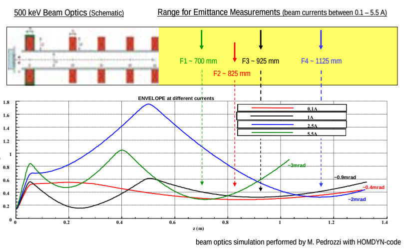
Pepperpot and YAG:Ce screen on sliders in UHV chamber



Out-coupling mirror and 5 lens optics (side view / cut)

500 keV Beam Optics (Schematic)

Range for Emittance Measurements (beam currents between 0.1 – 5.5 A)



beam optics simulation performed by M. Pedrozzi with HOMDYN-code

ε-Meter Requirements

ε-Resolution:	< 50	nmrad
Beam Sizes (σ):	300	mm
Meas. Range:	~ 0.5	m

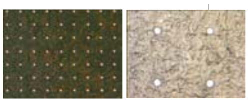
- PP and YAG:Ce-screen are retractable from electron beam
- online (in-situ) calibration is foreseen

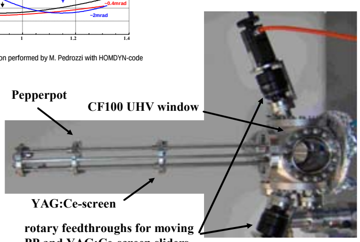
ε-Meter Parameters

Pepperpot-mask:		
- material: tungsten		
- thickness:	500	µm
- hole diameter:	20	µm
- hole distance:	150	µm
YAG:Ce screen:		
- thickness:	50	µm
- diameter:	5	mm
Optical System:		
- objective:	5 lens system	
- focal length:	800	mm
- magnification:	1:1	
- diameter:	102	mm
- flatness mirror:	λ/20	
window:	< 1 arcmin	
- resolution:	100	lp/mm
- CCD-type:	FireWire	
- pixel size:	4.65 x 4.65 µm	
- # of pixels:	1024 x 764	

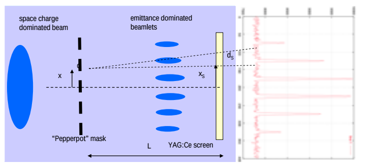
ε-Meter (UHV-chamber not assembled)

Tungsten Pepperpot





Pepperpot Emittance Measurement Principle

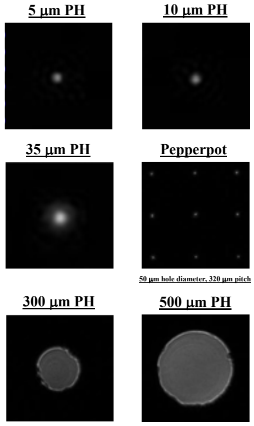


PP-Parameters to be measured

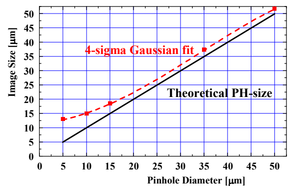
- L = distance between PP and screen
- d = PP hole diameter
- d_s = diameter of beamlet on screen
- x = distance of optical / central axis to PP hole
- x_s = distance of optical / central axis to beam spot on screen

- Beamlet profiles on the screen provide information of angular beam distribution at the position of the PP holes
  - ⇨ broadening of beamlets is a measure for the uncorrelated beam divergence
  - ⇨ beamlet position with respect to center of gravity is a measure for the correlated divergence
- Slope of particle's paths with respect to optical axis is given by: $x' = (x_s - x) / L$
- RMS emittance can be determined considering the second moments of x and x': $\varepsilon_{RMS} = 4 \left(\langle x^2 \rangle \langle x'^2 \rangle - \langle x\, x' \rangle^2 \right)^{1/2}$
- All parameters to be determined are geometrical values and can be measured with mm resolution

Images of Pinholes



Point Spread Function



- PSF has been measured in optical lab using a He-Ne laser source
- Gaussian fit with 4-σ (95% of intensity distribution) has been taken into account and leads to upper limit of ε-monitor PSF of 11.8 µm (optics & CCD) and 10.8 µm for optics alone
- out-coupling mirror and UHV-window were not part of the test set-up