THE FEL PROGRAM AT THE PEGASUS INJECTOR

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Abstract

The PEGASUS photo injector at UCLA can produce a photo-electron beam with a normalized emittance of 2 mm·mrad at an energy of 12-15 MeV, capable of driving a Free-Electron Laser in the mid IR regime. The FEL program, associated with the PEGASUS injector and presented here, is based on a Self-Amplifying Spontaneous Emission (SASE) FEL. The studies focus on increasing the efficiency of an FEL by novel undulator design and compensation of diffraction effects, using waveguides of millimeter size. In this presentation we also discuss the possibility of the PEGASUS FEL as a THz user facility.

INTRODUCTION

The PEGASUS Photo injector [1] is a novel standing-wave S-band structure for generating photo electrons and to accelerate them to 12 – 17 MeV. The high-brightness beam is suitable to drive a Self-Amplifying Spontaneous Radiation Free-Electron Laser (SASE FEL) [2] down to a wavelength of 10 μm without further acceleration.

The injector can also deliver the required beam to drive a Thomson backscattering source [3]: The mechanism is closely related to undulator radiation which is the basic radiation process of a Free-Electron Laser. Although the Thomson backscattering process does not amplify its own radiation as a SASE FEL does, the resonant wavelength lies in the X-ray regime, making this radiation source attractive to the scientific community.

We present here the possible applications for the PEGASUS injector, oriented towards light sources, spanning a range of THz radiation to X-rays. Other application are reported elsewhere [4].

INFRARED FREE-ELECTRON LASER

The FEL program is initiated with an existing undulator, previously used to demonstrate the first SASE FEL amplification of more than 5 orders of magnitude [5]. The 2 m long undulator consists of 98 periods with a period length of 2.05 cm. The configuration is planar and additional magnets supply equal focusing in both plane. The β-function is 22 cm.

With the expected beam parameters of the PEGASUS injector (Tab. 1, [6]) the SASE FEL resonates at 13 μm. Because the electron beam size is 170 μm and only one order of magnitude larger than the radiation wavelength, the diffraction during the FEL amplification is strong and lengthens the saturation length to 3 m.

Table 1: Electron beam parameters of the PEGASUS Injector

Energy	12 – 18 MeV
Energy Spread	0.15%
Emittance	4 mm·mrad
Charge	1 nC
Bunch Length	1 mm
Repetition Rate	1 – 5 Hz

Although we do not expect saturation, the radiation can be used to calibrate the IR diagnostics and to compare the measured performances with the predicted ones, based on start-end simulations with the codes PARMELA [7] and Genesis 1.3 [8].

The degradation due to diffraction can be overcome by embedding an IR waveguide within the undulator. The waveguide is a glass or silicon tube with a metal and dielectric layer deposited on the surface. Using silver and silver-iodide leyers of a few hundred nanometer each, the transmission is optimized for the wavelength region of interest. Measurements have shown losses of less than 2 dB over 2 m [9] and these hollow glass waveguides have already been successfully used for transportation of IR light [10].

The saturation length is reduced to 2 m with a 1 mm bore diameter of the hollow glass waveguide. Fig. 1 shows the performances for different bore diameters. The case for 5 mm differs only by a few percent from the free space case, excluding any waveguide. A 1mm diameter gives enough matching tolerance for the electron beam to the undulator focusing structure to avoid particle losses. The performance is insensitive to beam offsets or larger emittances. Although the waveguide is overmoded, the FEL eigenmode consists predominately of the fundamental TE mode of the empty waveguide.

THZ FREE-ELECTRON LASER

THz radiation sources are of particular interest to the science community [11] for various solid state, cluster and molecular studies. A tunable source such as a Free-Electron Laser is highly desirable. The undulator parameters are modified to increase the radiation wavelength without changing the energy of the driving electron beam. In order to radiate at 100 μm, which corresponds to a frequency of 3 THz, the period is increased to 5 cm and the undulator parameter to 1.5 at a beam energy of 15 MeV. A helical

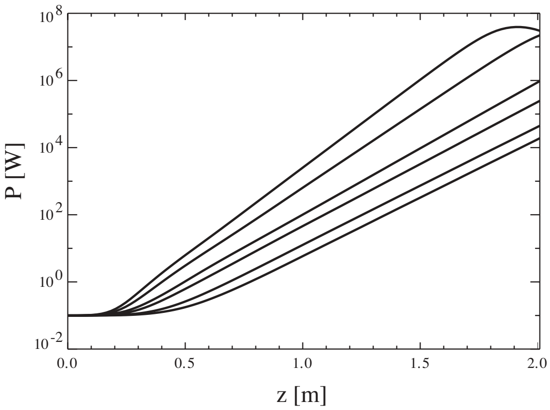

Figure 1: FEL performance of the PEGASUS IR waveguide FEL. The corresponding bore diameters are from the top: 0.8 mm, 1 mm, 1.5 mm, 2 mm, 3.5 mm, and 5 mm.

undulator has the advantage of increasing the output power and reducing the saturation length as compared to a planar undulator. The latter helps to reduce the impact of diffraction, which is even stronger than in the case of the IR FEL. In the gain guiding mode of the linear regime of the FEL the equilibrium radiation size is 2 mm. The impact of the strong diffraction yields an FEL performance very similar to the IR FEL, except for the wavelength. Three meters are required to reach saturation. Fig. 2 shows the radiation and current profile at saturation, which occurs at 3.5 m and the total energy of the radiation pulse is 120 μJ.

Although we have not studied the problem in detail yet, it is expected that an embedded waveguide will improve the performance of the FEL as is the case for the IR FEL. The aspect ratio between wavelength and bore diameter is smaller and the waveguide is less overmoded. This reduces the coupling to higher waveguide modes because the phase velocity is different and, thus, they are less synchronized to the electron beam.

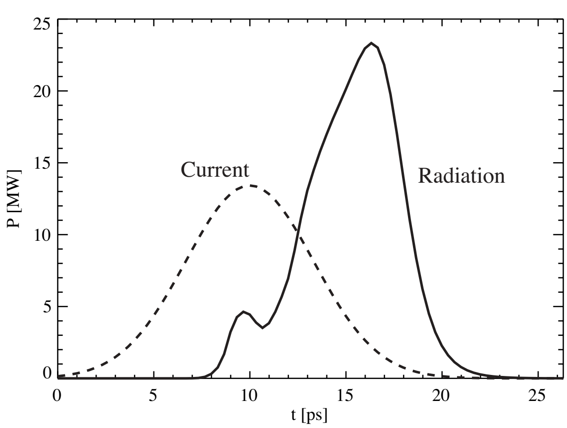

Figure 2: Radiation and current profile (solid and dashed line, respectively) at saturation for a THz SASE FEL.

THOMSON BACKSCATTERING X-RAY SOURCE

Thomson Backscattering is an alternative to multi-GeV electron beams and long undulators for a tunable X-ray radiation source. The necessary electron beam energy is between 10-50 MeV for a wavelength of 800 nm of the scattering laser. Despite the fact that the process lacks the collective instability of the FEL and emits on the spontaneous radiation level, the reduced size of the driving linear accelerator and the existence of TW drive laser makes this radiation source attractive. The obtained pulse length are comparable to those of an Free-Electron Laser such as LCLS [12] or TESLA FEL [13].

With the high-brightness electron source of the PEGASUS injector, a Thomson backscattering source becomes feasible. A schematic of the beam line and the drive laser is shown in Fig. 3. There are two different method of operation. With an incident angle of 90 degrees the pulse length of the X-ray pulse is determined by the shorter length of the electron or laser pulse: for a reasonable focused 50 – 100 fs Ti:S laser it is around 100-200 fs. However the overlap of the laser pulse with the electron beam is minimal, resulting in a rather low photon flux of about $2.1 \cdot 10^5$ photons per pulse, based on the parameter given in Tab. 2.

A head-on collision maximizes the overlap between the electron beam and the laser pulse. The flux is three order of magnitude higher ($1.0 \cdot 10^8$) but the X-ray pulse is stretched to 3 ps. In this case the wavelength is 2.2 Å – twice as short as for the 90 degree incident case.

We are considering a set-up which allows the operation of both 90 and 180 degree incident angle. The required instrumentation for X-ray transport and diagnostic has to be further studied.

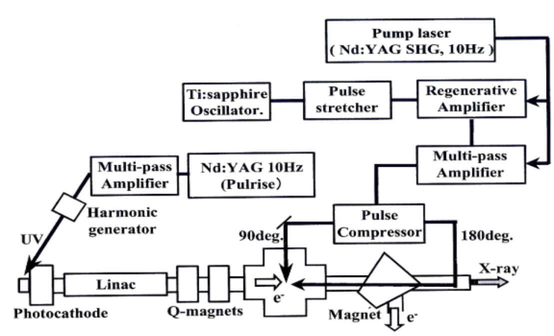

Figure 3: Schematic layout of a Thomson backscattering X-ray source at the PEGASUS injector.

CONCLUSION

With the compact design of a high-brightness photo electron beam source the applications of Free-Electron Lasers and the related Thomson backscattering process become feasible and attractive. In particular the small scale of the

Table 2: Expected performance of the Thomson Backscattering X-ray source at the PEGASUS injector.

Incident Angle	90°	180°
Wavelength	4.4 Å	2.2 Å
Pulse Length	250 fs	3 ps
Photon Flux	$2.1 \cdot 10^5$/pulse	$1.0 \cdot 10^8$/pulse
Opening Angle	33 mrad	33 mrad

required space is appealing as a tunable radiation source "on location" for a wide class of science experiments instead of the remote location of light sources such as APS, ESRF or Spring 8 [14].

The prospect of a light source for the PEGASUS lab can be enhanced with the combination of the Thomson backscattering experiment with the THz SASE FEL, both attractive to the science community. The backscattering process does not degrade the beam quality of the electron beam and, thus, allows for a downstream operation of the THz FEL. A delay line of the X-ray pulse is required for pump-probe experiments with the THz pulse. It is desirable to use a variable-gap undulator for the THz FEL, so that an independent tuning of the X-ray and THz wavelength is possible.

REFERENCES

[1] X. Ding et al., Proc. of the Particle Accelerator Conference, New York, 1999

[2] R. Bonifacio, C. Pellegrini, and L.M. Narducci, Opt. Comm. **50** (1984) 373; A.M. Kondradenko and E.L. Saldin, Part. Accel. **10** (1980) 207

[3] K.-J. Kim, S. Chattopadhyay, C.V. Shank, Nucl. Instr. & Meth. **A341** (1994) 351

[4] G. Andonian *et al.*, Presented at this conference

[5] M. Hogan *et al.*, Phys. Rev. Lett. **81** (1998) 4867

[6] J.B. Rosenzweig *et al.*, Proc. of the Particle Accelerator Conference, New York, 1999

[7] L.M. Young and J.H. Billen, *PARMELA*, LA-UR-96-1835 (2000)

[8] S. Reiche, Nucl. Inst. & Meth. **A 429** (1999) 243

[9] Y. Matsuura *et al.*, Appl. Opt. **34** (1995) 6842

[10] H.S. Pratisto *et al.*, Clinical beam delivery of the Vanderbilt FEL: Design and performance of a hollow waveguide-based handheld probe for neurosurgery, in: *Specialty Fiber for Medical Application*, J. Harrington, A. Katzir (eds), SPIE, Bellingham, (1999)

[11] Proc. of the 27th International Conference on Infrared and Millimeter Waves, R. J. Temkin, Ed. (2002)

[12] *Linac Coherent Light Source (LCLS)*, SLAC-R-521, UC-414 (1998)

[13] *TESLA – Technical Design Report*, DESY 2001-011, ECFA 2001-209, TESLA Report 2001-23, TESLA-FEL 2001-05, Deutsches Elektronen Synchrotron, Hamburg, Germany (2001)

[14] V. Litvinenko, *Storage Ring-based Light Sources*, Proc. of the 17th Advanced Beam Dynamics Workshop on Future Light Sources, Argonne, USA, 1999