FUTURE PLANS FOR DELTA

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Abstract

DELTA is a 1.5-GeV synchrotron radiation source at the TU Dortmund University (Germany). This paper reviews the status of the facility and describes its new projects. Among other activities, it is planned to generate ultrashort and coherent VUV pulses by seeding the existing FEL in its optical-klystron configuration with femtosecond laser pulses and to produce higher harmonics.

INTRODUCTION

The Center for Synchrotron Radiation at the TU Dortmund University in Germany operates the electron storage ring DELTA as a synchrotron radiation source for internal and external users and as a facility for accelerator physics research. Presently, the annual operation time is 3000 hrs with an availability above 90%.

As shown in Fig. 1, electrons from a 60-MeV S-band linac are accelerated by a booster synchrotron (BoDo) to the full energy of 1.5 GeV and injected into the storage ring. The ring circumference is 115.2 m, the rf frequency is 500 MHz. The beam lifetime at the maximum multi-bunch current of 130 mA is 6-10 hrs. Two dipole beamlines are presently in operation and one more is under constuction. Two beamlines deliver hard-x-rays from a superconducting asymmetric wiggler (SAW) [1]. A permanent-magnet undulator (U-55) and an electromagnetic undulator (U-250) serve one soft-x-ray beamline each.

With mirrors at either end, the U-250 can be operated as a free-electron laser (FEL) in two configurations, (i) with all 19 periods powered equally or (ii) as an optical klystron with two undulators of 7 periods each and the central poles providing a dispersive chicane. The period length is 25 cm, the maximum field parameter is $K = 5$, limited by the power supplies. First lasing of the FEL (FELICITA I) was achieved in 1999 at wavelengths of 420-470 nm [2]. More recently, its stability was significantly improved by a new mirror chamber design and the FEL process was studied in detail by streak camera measurements [3].

Several new projects to improve the facility or to extend its capabilities are in progress or planned for the near future, and will be described in the following.

ULTRASHORT RADIATION PULSES

The pulse duration of synchrotron radiation is typically 30-100 ps, whereas many phenomena on the atomic level - such as chemical reactions, phase transitions, lattice vibrations, etc. - occur on the sub-ps time scale, which has become accessible with the advent of femtosecond (fs) lasers, in particular the Ti:sapphire laser operating at a wavelength of 800 nm. Time-resolved studies at shorter wavelengths are possible by employing high-harmonic generation (HHG) or radiation from laser-induced plasmas with their respective merits and shortcomings.

FELs are excellent short-pulse sources, delivering pulses with a peak brilliance 8-9 orders of magnitude higher than that of conventional synchrotron radiation and a pulse duration of a few 10 fs. However, to-date only two FELs in the VUV regime are in operation: FLASH [4] at DESY/Hamburg and SCSS [5] in Hyogo/Japan. Even though others are to follow, e.g. LCLS at SLAC in 2009, linac-based FELs are unable to serve many users simultaneously and are limited in their pulse repetition rate. Thus, they will not replace synchrotron light sources, but will provide radiation with complementary properties. It is therefore of great interest to extend the capabilites of conventional synchrotron radiation facilities to shorter pulse duration. Several methods to this end have been devised.

• Reducing the bunch length to a few ps by reducing the momentum compaction factor ("low-α" optics) is routinely practiced e.g. at BESSY in Berlin [6].

• Creating a longitudinal-transverse correlation by transversely deflecting rf cavities and compressing the radiation pulses by optical methods to 1-2 ps has been proposed [7] and studied by simulations [8], but is not yet implemented anywhere.

• Modulating the electron energy by fs laser pulses and transversely displacing the off-energy electrons by dispersion ("femtosecond slicing" [9]) has been imple-

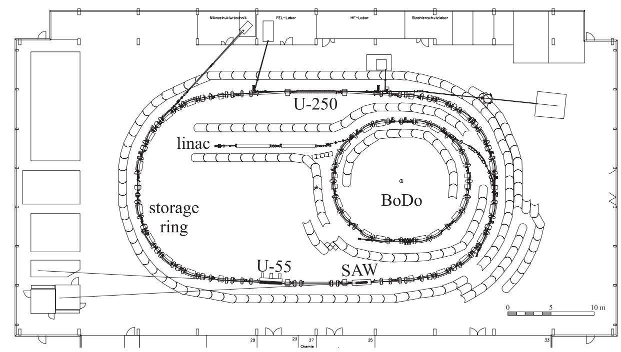

Figure 1: DELTA floorplan. The facility comprises a 60-MeV linac, a booster synchrotron (BoDo) and a 1.5-GeV electron storage ring, including three insertion devices (SAW, U-55, U-250).

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mented at the Advanced Light Source/Berkeley [10], at BESSY/Berlin [11] and at the Swiss Light Source [12] with pulse durations of 100-300 fs.

• Converting a laser-induced energy modulation into a density modulation gives rise to ultrashort (50-100 fs) coherent radiation at harmonics of the laser wavelength. This "coherent harmonic generation" (CHG) has been demonstrated e.g. at ELETTRA/Italy [13] and UVSOR II/Japan [14].

With the FEL undulator at DELTA in its optical-klystron configuration, CHG pulses can be generated once a fs laser system has been installed. The properties of CHG radiation

• high intensity $\sim$ (number of electrons)^2
• high degree of longitudinal and transverse coherence
• pulse duration essentially that of the laser ($\sim$50 fs)
• perfect synchronization with an external laser system

allow for experiments which cannot be performed with conventional synchrotron radiation. The time resolution in pump-probe experiments is improved by three orders of magnitude. The high coherence allows e.g. phase-contrast images or holographic applications with high intensity, while synchrotron radiation has to be strongly collimated to achieve sufficient transverse coherence [15]. One disadvantage of CHG is the restriction in repetition rate, being equal to that of the laser, another is the wavelength limitation to the 3-5th harmonic of the initial radiation. On the other hand, the laser pulses can be converted to smaller wavelengths before entering the optical klystron and the restriction to integer fractions of the laser wavelength can be relaxed by employing an optical parametric amplifier.

Figure 2 shows the CHG principle and the setup at DELTA. One aim of the planned research program is to establish ultrashort pulses in stable routine operation for users, which requires to increase the U-250 field parameter in order to be resonant to 800 nm at the nominal beam energy of 1.5 GeV. Another aim is to extend CHG to smaller and tunable wavelengths and to smaller pulse duration. As a later upgrade, a "slicing" source can be constructed by adding another undulator.

After a fraction of the storage ring circumference, the energy modulated electrons will be longitudinally displaced due to the non-isochronicity of the lattice, leaving a short gap in the electron bunch which gives rise to coherent radiation in the Terahertz (THz) regime. This radiation provides a very sensitive signal to detect and optimize the overlap between electron bunches and the laser pulses [16]. In addition, the THz pulses have a duration of only a few 100 fs and are perfectly synchronized to the laser, which makes them ideally suited for time-resolved IR-spectroscopy studies. Therefore, a beamline extracting THz radiation from a subsequent dipole magnet is an indispensable part of the planned short-pulse facility at DELTA.

The laser-electron interaction plays a key role in the development of seeded FELs. Discrepancies between expected and achieved laser-induced energy modulation were reported repeatedly [10, 11] and are probably due to imperfect overlap between electrons and laser pulses or laser

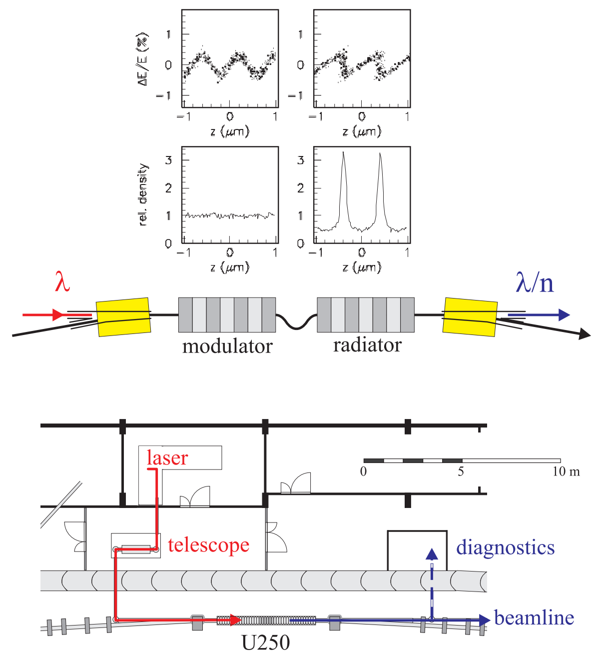

Figure 2: Principle of coherent harmonic generation (top): laser pulses of wavelength λ co-propagating with electrons in an undulator ("modulator") cause a periodic modulation of the electron energy, which is converted into a density modulation by a magnetic chicane and gives rise to coherent radiation in a second undulator ("radiator"). This radiation occurs at wavelength λ and harmonics thereof. The setup at DELTA (bottom) comprises a femtosecond laser system, the U-250 undulator, diagnostics and a synchrotron radiation beamline.

abberations. Due to their high bunch rate and stable beam, electron storage rings like DELTA are well suited for systematic experimental studies of the laser-electron interaction in view of future radiation sources. Other applications of a fs laser system at DELTA include laser-based diagnostics, e.g. laser wires or electro-optical sampling, and the generation of short hard-x-ray pulses by Compton backscattering.

BEAM STABILITY

The beam of the DELTA storage ring is subject to external influences like ground vibrations (around 10 Hz), the mains frequency (50 Hz) and its harmonics, crosstalk from the ramp cycle of the adjacent synchrotron, changes of insertion device settings, and others. Orbit feedback systems detecting and correcting the beam position at a kHz rate are doing a good job at several facilities, e.g. [17], and are often based on DSP boards (digital signal processors) developed for this purpose. The time to develop such a complex system, however, can easily exceed the short DSP development cycle. At DELTA, the construction of a fast global orbit feedback based on commercially available FPGA boards (field programmable gate arrays) is underway [18]. As a prototype, a local orbit feedback enclosing the U-250 undulator has already been tested successfully [19]. One purpose of the project is to improve the stability of the beam at DELTA, another is to establish a cost-effective and sustainable system design suitable for other facilities as well. To this end, a collaboration between DELTA, FZJ (Jülich/Germany) and GSI (Darmstadt/Germany) has been set up to develop fast orbit feedback systems in view of hadron accelerators and storage rings at FAIR (Facility for Antiproton and Ion Research) [20].

The beam current of 130 mA at DELTA is above the threshold of a longitudinal coupled-bunch instability (mode number 54) [21]. The origin of the impedance causing this instability is unknown. The oscillation can be suppressed by phase-modulating the voltage of the fundamental mode of the rf cavity [22]. It is nevertheless planned to counteract this and other potential coupled-bunch oscillations by installing a bunch-by-bunch feedback system. For this purpose, commercially available feedback electronics can be used in combination with a longitudinal kicker cavity originally developed at DAΦNE/Frascati [23] and adapted to an rf frequency of 500 MHz at BESSY/Berlin [24].

FREQUENT INJECTION

Presently, the DELTA storage ring is filled every 8 hrs. A more frequent injection would raise the average beam current and thus reduce the variation of the heat load on the storage ring itself and on the beamline elements. Several modes of operation are conceivable:

• Injection every 1-2 hrs with 20-30 mA variations of the beam current is possible without further alterations, if the beam shutters are closed during injection.

• Frequent injection every 20-30 min with a current variation of 10 mA while keeping the beam shutters open was proposed in [25] and the technical feasibility of this mode has been demonstrated. However, injection with open beam shutters raises radiation safety concerns and requires a modification of DELTA's operating permit.

• Topping up every 30-60 sec, again with open beam shutters, would keep the beam current constant on the subpercent level. In this mode of operation, the injection chain (gun, linac, synchrotron) would be operated almost continuously. The crosstalk from the synchrotron ramp cycle as well as the influence of the pulsed magnets (kicker, septa) on the stored beam position must be eliminated.

The preferred mode of operation is presently under discussion, since the user requirements regarding stability, integrated photon flux, constancy of heat load and time between interruptions depend on the respective experiment. In terms of photon flux and heat load, topping up is clearly preferrable. As for the crosstalk from the synchrotron, the installation of a fast orbit feedback as discussed above could resolve the issue. If the beam disturbance from the pulsed elements cannot be ignored, data acquisition may be suppressed for a few damping times.

OUTLOOK

The projects described in this paper and others not discussed here - such as improving the injection chain, beam-based alignment [26], measuring the optical functions and coupling, etc. - are either underway or in preparation. Work on a fast orbit feedback has started already in 2008, and two dissertations will be devoted to this issue. The installation of a fs laser system to generate ultrashort radiation pulses is planned for early 2010, and preparatory work is in progress.

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