FEL PROJECTS AT DELTA*

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ABSTRACT

This paper reports on the plans for a new FEL facility at the 1.5 GeV electron storage ring DELTA [1] under construction at the University of Dortmund. First, the concept of this three-stage long-term project is sketched, with FEL's planned in the wavelength regime from the visible to wavelengths below 20 nm. In the following, the first two FEL projects are discussed in more detail.

LONG TERM CONCEPT OF THE DELTA-FEL FACILITY

DELTA is a low-emittance electron storage ring with two about 20 m long straight sections freely available for insertion devices. Working at low energies of about 500 MeV, it is an excellent driver for FEL's from the visible to the XUV. [1]

The project will be started with a simple and inexpensive device producing visible light. Secondly, it is planned to proceed to a high-gain FEL oscillator [2], and finally, with the experience gained so far, FEL operation below 20 nm will be attempted with a single-shot high-gain FEL.

The first device, FELICITA I, has to fulfill the following options. It has to be simple, easy to operate and will work at wavelengths, where all necessary optical equipment is well developed and available. On the other hand, the design of FELICITA I has to be as flexible as possible, but has to provide high gain to guarantee save operation above the oscillator threshold. Therefore, the project will start with an electromagnetic undulator, designed to operate in two different modes, namely as an optical klystron [3] and as a conventional FEL. Using this device it is intended to generate radiation at about 400 nm with DELTA running at 500 MeV. As the next step, it is planned to operate FELICITA I in oscillator mode at wavelengths down to 200 nm by running DELTA up to 700 MeV. Losses in gain due to the higher electron energy beam will be compensated by higher peak currents, since collective instabilities and other current-limiting effects as Touschek effect [4] or intra-beam scattering [5] are not as severe as at low energies. With beam energies of about 1.0 GeV, FELICITA I will produce radiation of wavelengths of about 100 nm, that can be used to test and improve optical components.

From the experience gained so far, DELTA will be optimised, to provide better low energy performance for the second experiment FELICITA II at 100 nm wavelength and below. Since mirrors with more than about 50 % reflectivity are not available [6] at these wavelengths, FELICITA II has to provide gain of 3 or more. As in the case of FELICITA I, this device will operate at energies from 500 MeV up to 1.0 GeV with nearly constant gain. Losses in gain due to the higher energy are compensated by higher peak currents attainable at these energies.

The third FEL project at DELTA is proposed to operate at wavelengths below 20 nm. In this region the operation of a single-pass FEL, installed in a pulsed-mode by-pass is the best solution [7]. The electron beam is kicked once through the by-pass into the FEL, producing a single but very intense laser pulse. Due to this process, the beam quality is degraded seriously. Therefore, the beam has to cool down by synchrotron radiation damping, before it can be reinjected into the FEL by-pass again. Due to the short damping time of DELTA, pused-mode FEL operation with frequencies of 10-20 Hz is realistic.

Besides of better storage ring performance without FEL's, a by-pass dedicated to FEL experiments provides certain advantages. First, the optical cavities can be made shorter, because FEL operation is possible with 3, 4 or 6 electron bunches instead of one- or two-bunch operation only. Moreover, a by-pass with separated beam line for the FEL provides free access for manipulating mirrors etc. during storage ring operation. Inserting an extra chicane in the bypass for FELICITA I, allows to operate with a very short optical cavity.

FELICITA I

FELICITA I will be the first FEL device to be built in a series of storage-ring FEL experiments. It has to be a simple, compact, most flexible and inexpensive device, but has to operate with rather high gain. To avoid problems with optical components, it is designed to operate in the visible first.

These conditions lead to an electromagnetic undulator, made of 16 identical periods. Such an undulator can be split into several sections, simply by exciting the coils of various periods with different currents, the same experimental setup can be used either as an optical klystron (OK) or, alternatively, as a conventional FEL. In contrast to the FEL mode, with all periods held on the same field, in the OK mode the undulator is devided into three sections. The first and the last seven periods are used as two identical undulators, separated by the two central periods driven at higher field and serving as dispersive section.

In the OK mode FELICITA I operates with much higher gain than in the FEL mode, but due to the small linewidth of the gain curve, only low average output power can be extracted [8]. Save ope-

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UNDULATOR		OK MODE	FEL MODE
Period Length	l_o [m]	0.25	0.25
Peak Field	B_o [T]	0.09	0.09
K - Value	k^u	2.1	2.1
Period Number	n_u	7	16

DISPERSIVE SECTION			
Peak Field	B^d_o [T]	0.69	/
K - Value	k^d	16	/
Period Number	n_d	2	/
Normalised Strength	N_d*	80	/

* optimised for 0.1% energy spread

Tab. 1: Parameters of the electromagnetical Undulator

BEAM PARAMETERS		OK Mode		FEL Mode	
Energy	[MeV]	500	1000	500	1000
Resonant Wavelength	[nm]	418	104	418	104
Average Current*	[mA]	30	60	30	60
Peak Current**	[A]	90	180	90	180
Filling Factor		0.81	0.81	0.81	0.81
Gain Degradation		0.34	0.34	***	
Max. Gain	[%]	10.4	10.3	4.0	3.9
Gain / Peak Current	[10^{-4}]	11.6	5.7	4.5	2.2

* per bunch, 4 bunches
** assuming 1.5 cm RMS. bunchlength
*** working in the Homogenous Broadening Regime [10]

Tab.2: Expected performance of FELICITA I

ration above oscillator theshold is expected for both operation modes and wavelengths about 400 nm. But at a later stage, progressing down to the UV, OK operation will be more favorable, because of the strongly reduced reflectivities of the mirrors of the optical cavity. With the OK-option, oscillator operation down to 200 - 300 nm is expected, which is particularly interesting for chemical, biological and medical applications [9].

Operating DELTA at 1.0 GeV, FELICITA I provides an intense radiation source for testing and developing optical components, suitable for the second experiment.

FELICITA II

Due to the expected high losses of optical cavities at wavelengths below 100 nm, XUV-FELs have to provide much more gain per pass compared to the visible regime [6].

To compensate mirror losses on the order of 50 % per reflection, gain factors of about 3 - 5 are necessary to reach the oscillator threshold. Such high values can only be attained by the use of very long undulators with many periods. Therefore, FELICITA II will be an undulator of 225 periods of 6.2 cm each and total length of 14 m, built in hybrid permanent magnet technology.

With DELTA running at energies up to 1.0 GeV, this device will produce FEL radiation in the range from 100 nm down to 25 nm.

Period Length l_o	[m]	0.062	
Peak Field B_o	[T]	0.35	
K - Value k_u		2	
Period Number n_u		225	
Beam Energy	[Mev]	500	1000
Resonant Wavelength λ_r	[nm]	100	25
Average Current*	[mA]	50	100
Peak Current**	[A]	150	250
Gain Degradation Factor***		0.3	0.3
max. Gain****		5.5	2.1

* per bunch, 2 bunches
** assuming 1.5 cm RMS. bunchlength
*** calculated according to Bizzari et al [9]
**** calculated with a onedimensional FEL simulation code [11]

Tab. 3: Parameters of FELICITA II

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