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POSSIBLE FEL PROJECTS AT DELTA*

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Abstract This paper presents the concept of the new FEL facility at the 1.5 *GeV* electron storage ring DELTA[1], currently under construction at the University of Dortmund. Furthermore, detailed information about the first FEL experiment (FELICITA I) are given.

THE CONCEPT OF THE DELTA FEL FACILITY

DELTA is a low-emittance electron storage ring with 1.5 *GeV* maximum energy. Two about 20 *m* long straight sections, available for insertion devices, make this ring an excellent driver for FEL experiments. Corresponding to different electron-beam-energies the FEL wavelengths run from the visible down to the XUV. Since the short wavelength operation of FEL's — the main goal of the DELTA FEL facility — is a very ambitious experiment, a concept is proposed to reach the short wavelength regime within several steps. Such a concept enables the DELTA group to start from save experiments to gain the experience, required for the more ambitious XUV storage–ring–FEL.

Therefore, the project will start with a rather simple device, FELICITA I (Free Electron Laser In a Circular Test Accelerator) operating in the visible. Second, a high-gain FEL oscillator is planned, operating at wavelengths of about 100 *nm*. Finally, with the experience gained so far, FEL operation at wavelengths about 20 *nm* will be attempted in a third experiment, maybe using a single shot high-gain FEL.

To start with a very flexible but also not very complicated, compact and inexpensive device the first experiment will be realized using an electromagnetic undulator, providing two different operation modes, as a conventional FEL as an optical klystron (OK)[2]. This possible choice between two different operation modes is a very interesting feature, since this laser can be operated with higher gain in OK mode, but also with higher efficiency in FEL mode. To avoid complications with mirrors or optical equipment in general, it is planned to start the experiments in the visible wavelength regime, with DELTA running at low energy of about 500 *MeV*. After save oscillator operation in the visible it is planned to run FELICITA I in

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OK mode at higher beam energies, proceeding to wavelengths in the UV. Oscillator operation is expected down to wavelengths of about 200 *nm*, using electron beam energies up to 800 *MeV*. Losses in gain are thought to be overcompensated by better accelerator performance, because current limiting effects such as Touschek effect[3] or intra–beam–scattering[4] are not as severe as at low energies. Pushing FEL operation below 200 *nm* may not lead to successfull lasing, but offers the possibility to do first experiments with mirrors in the wavelength regime of about 100 *nm* and considerably below.

During the operation of the first experiment, DELTA will be optimised to provide good low energy performance, especially high peak currents and low emittance. Both features are essential for the next projects. The second step, called FELICITA II, will use an approximately 14 *m* long permanent magnet undulator with 225 periods (see *TABLE 1*). With DELTA running at 500 *MeV*, this device is designed to produce gain values of 3 - 5, necessary to compensate for the mirror losses of about 50 % in the wavelength regime below 100 *nm*[5]. Running at higher energies up to about 1.0 *GeV* first experiments at wavelengths down to 25 *nm* are possible.

TABLE I Preliminary design data of the second FEL experiment FELICITA II.

UNDULATOR				
Period Length	L_o	[m]	0.062	
Mag. Peak Field	B_o	[T]	0.35	
K - Value	k^u		2	
Period Number	n_u		225	
Beam Energie	E_b	[MeV]	500	1000
Resonant Wavelength	λ_r	[nm]	100	25
Average Current in 2 bunches	$\bar{I}$	[mA]	100	200
Peak Current	$\hat{I}$	[A]	150	250
Gain Degradation[8]	f_g		0.3	0.3
Max. Gain	G_{max}		5.5	2.1
Average Outputpower	P_{out}	[W]	0.37	11.96

Both experiments, discussed above, are necessary steps towards the X-UV operation of FEL's in storage rings. Futhermore, the wavelength regimes of the first experiment, but also of the second and the third experiment are overlapping. Thus, components of a later stage of the experiments can be developed and tested at a prior stage.

Depending on the results of FELICITA I & II, the decision on the type of the third project will be made.

THE FIRST EXPERIMENT FELICITA I

As mentioned before, the FEL experiments at DELTA will start in the visible wavelength regime. The first device has to be a rather simple, compact most flexible and inexpensive device, but has to operate with rather high gain. Choosing electron beam energies of about 500 MeV, an energy expected to be considerably above the lower limit of the DELTA energy range, undulator periods on the order of 25 cm are appropriate. Furthermore, the k–value of the FEL undulator should be kept as low as possible, to avoid additional problems due to mirror degradation.

All these requirements can be fulfilled with an electromagnetic undulator, made of 16 periods. Since such an undulator can be operated with all periods driven by the same current, but also divided into several sections by choosing different currents for these sections, this device offers several possibilities. First, with all periods at the same field, it can be operated in conventional FEL mode. This operation mode provides only moderate gain on the order of a few percent, but rather high output power[6]. In contrast high gain, but less output can be produced by operating the same device with the central periods driven by much higher currents. Therefore, FELICITA I is a very flexible device, offering FEL and optical klystron operation mode.

The undulator (*FIGURE 1*) has to fulfill several conditions which determine its design. In order not to give an angular deflection to the beam, it must be ensured that $\int B \cdot ds$ equals zero for all modes of operation. Furthermore, it has to be a cosine undulator in order to avoid horizontal displacement of the beam. Therefore, the first and last pole must have half the strength of a normal pole. This holds not only for the whole undulator but also in OK mode for the leading and the trailing undulator and the dispersive section.

Assuming infinitely wide polefaces in horizontal direction, the magnetic field of one period can be described by the following Fourier series:

$$B_y(s) = a_0 + \sum_{i=1}^{\infty} a_i \cdot cos(\frac{2\pi i}{l_0} \cdot s) + b_i \cdot sin(\frac{2\pi i}{l_0} \cdot s)$$

where $l_0 = 0.25\ m$ is the length of a period.

A figuere of merit for the field quality is given by the ratio:

$$Q = \sqrt{\frac{a_1^2}{\sum_{i=1}^{\infty}(a_i^2 + b_i^2)}}$$

As a_1 is the desired component and all other Fourier coefficient should be negligible compared with it, the ratio defined above should be as near to one as possible. As a consequence of these conditions the undulator was designed as follows. The undulator is made of 16 periods, 0.25 m each, giving an overall length of 4.00 m. It consists of identical poles with the exception of the two half poles at the ends. The shape and the width of the poles is optimized with the aid of the code POISSON[7] in order to obtain the desired field configuration. It was checked that the peak value of the magnetic field in iron does not exceed 2.0 T resulting in a saturation of less than 5 % for a maximum field of 0.7 T in the dispersive section.

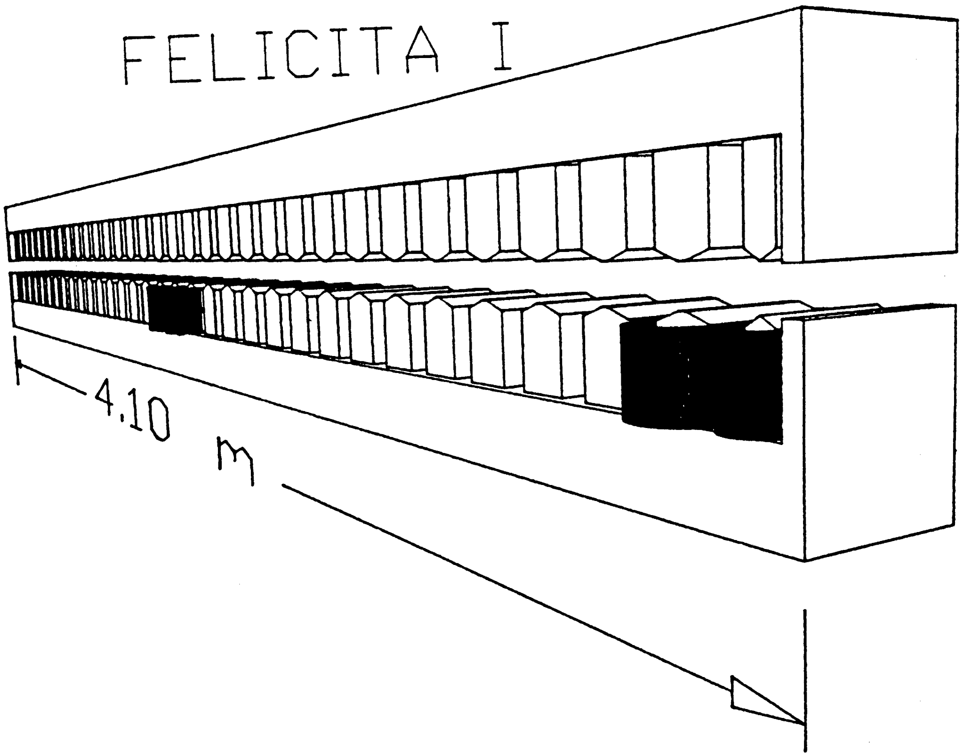

FIGURE 1 The FELICITA I Undulator

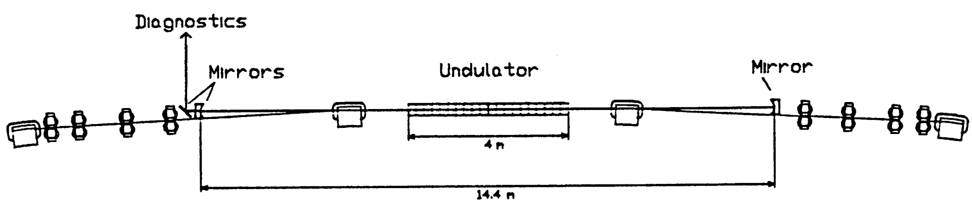

FIGURE 2 Experimental setup for FELICITA I

TABLE II Parameters of the FEL undulator for FELICITA I for FEL and OK and expected data. Operation at 418 nm and 104 nm wavelength. The data given here, are worst case estimates.

UNDULATOR			OK MODE		FEL MODE	
Period Length	L_o	[m]	0.25		0.25	
Mag. 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						
Mag. Peak Field	B_d	[T]	0.7		/	
K - Value	k^d		16.0		/	
Period Number	n_d		2		/	
Normalized Strength	N_d		80		/	
EXPECTED OK– and FEL PERFORMANCE						
Beam Energie	E_b	[MeV]	500	1000	500	1000
Resonant Wavelength	λ_r	[nm]	418	104	418	104
Average Current in 4 bunches	$\bar{I}$	[mA]	120	240	120	240
Peak Current	$\hat{I}$	[A]	90	180	90	180
Filling Factor	FF	[%]	0.81	0.81	0.81	0.81
Gain Degradation[8]	f_g		0.34	0.34		
Max. Gain	G_{max}	[%]	10.4	10.3	4.0	3.9
Gain / Peak Current	$G/\hat{I}$	[10^{-4}]	11.6	5.7	4.5	2.2
Average Outputpower	P_{out}	[W]	1.05	33.6	6.3	201.8

The undulator is powered by two separated current circuits, one for the leading and trailing undulator sections and one for the central periods to produce either a continous undulator field, or to power the central coils with a higher current in order to obtain the higher field in the dispersive section for OK operation. The two intersecting poles are excited each by two half coils, one from the outer and one from the central circuit. In this way it is ensured, that $\int B \cdot ds$ equals zero for arbitrary chosen currents in both circuits, beside of iron saturation effects, which are small and can easily be compensated by correction coils.

The optical cavity, that will be used for the first experiments, is designed for four-bunch operation of DELTA. It is 14.4 m long and placed in one of the two straight sections. In combination with a special optics in the straight section, it forms the experimental setup for FELICITA I, presented in (*FIGURE 2*).

In case of FELICITA I, the short matching dipoles at the begining and end of the straight section used with a deflection angle of 7° only, instead of 10°. In order to match all optical functions with respect to the symmetry point in the center of the undulator, four quadrupoles are needed. Two additional weak bendings, providing an additional deflection of 3° steer the electron beam into the undulator. In this way the amplified laser beam and the electron beam are separated. The distance of the two beams is of about 20 *cm* at the mirrors of the optical cavity. With DELTA running at electron energies about 500 *MeV*, FELICITA I will operate in wavelength regime of about 400 *nm*. The gain depending on the operation mode, is expected in the range between 4 – 10 %. These values are more than sufficient to reach the oscillator theshold in the visible.

After first experiments in the visible, FEL experiments operating at higher electron beam energy are planned. The maximum gain of FELICITA I is expected to stay at about the same value, because losses in gain due to the higher energy will be compensated by higher peak currents due to better accellerator performance. As the mirror reflectivity drops towards the UV, oscillator operation of FELICITA I is expected to wavelengths down to about 200 *nm*, but even in OK mode. Driven with beam energies of 1 *GeV*, FELICITA I will produce radiation of 100 *nm* wavelength. In this wavelength regime only the spontanous radiation can be used, as gain values of about 10 % are much to small to compensate for the mirror losses. But this short wavelength operation offers the possibility to investigate in optical components for the following UV–FEL experiments.

CONCLUSION

The new storage-ring DELTA offers the possibility of FEL reseach in the wavelength regime from the visible down to the XUV. The first experiment FELICITA I will be a two–in–one–undulator, permitting FEL and OK operation in the wavelength regime from 400 down to 200 *nm*.

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