Particle Accelerators, 1990, Vol. 33, pp. 27–32
Reprints available directly from the publisher
Photocopying permitted by license only

THE DORTMUND ELECTRON TEST ACCELERATOR "D E L T A", A NEW LOW-EMITTANCE STORAGE RING OF 1.5 GeV

NIELS MARQUARDT
DELTA Group*
Institute of Physics, University of Dortmund,
P.O.Box 500 500, 4600 Dortmund 50, Germany

Abstract A new low-emittance electron storage ring has been designed at the University of Dortmund, the construction of which starts now. The intention of this facility is to provide test possibilities for accelerator research and synchrotron-radiation instrumentation and to foster the development of compact high-brightness photon sources, of accelerator components, and of various insertion devices. Of particular interest is the development of FEL's in the UV and VUV range (λ < 20 nm). To a limited extent DELTA will be used as a light source for short-term single-user experiments exploiting very special beam qualities, i.e. a particular time structure, high-current single-bunch operation or low-beta focusing for micro-undulator operation. The facility consists of a 100 MeV LINAC, a booster synchrotron BODO which can operate also as a storage ring, and the main storage ring DELTA. The large flexibility of the DELTA lattice with two 20 m long dispersion-free straight sections allows to run with different beam optics and is optimized for FEL operation.

INTRODUCTION

The Dortmund ELectron Test Accelerator DELTA [1,2] currently under construction at this University is a third-generation synchrotron light source of maximum energy of 1.5 GeV covering different ranges of photon energies. It is aiming at improving the spectral brilliance by several orders of magnitude by optimizing the storage ring magnetic lattice for low emittance and very high circulating currents and by extensive use of magnetic-insertion and free-electron-laser devices. For such experiments one can choose optics with emittances as low as $\epsilon = 4 \cdot 10^{-9}$ m rad at 1 GeV. However, one of the design goals of the DELTA lattice is its large flexibility which also provides normal operation with standard optics of emittances of $\epsilon = 2 \cdot 10^{-8}$ m rad and emittance values as large as $\cong 10^{-7}$ m rad.

---

* B. Baasner, C. Biermann, F. Brinker, S. Brinkmann, J. Friedl, R. Heisterhagen, N. Marquardt, M. Michel, M. Negrazus, D. Nölle, M. Schürmann, K.Wille, V. Ziemann

Besides its low emittance the DELTA lattice with its triplet focusing structure and strong bending fields guarantees also short synchrotron damping times and, due to an effective sextupole arrangement, a reasonably large energy acceptance of at least $\Delta p/p = 2\%$.

The new facility uses a 100 MeV electron LINAC and a 1.5 GeV slowly ramped booster synchrotron, called **BODO** (BOoster DOrtmund), for full-energy injection into the 1.5 GeV storage ring DELTA (see Figure 1). This main machine with a circumference of 115.2 m consists of two half-circular arcs separated by two 20 m long, straight sections without dispersion, providing space for extremely long undulators. A rather conventional stainless-steel (316 LN) vacuum chamber of small cross-section has been designed with one antechamber at its inner circumference for continuously pumping with a combination of integrated DIP's and NEG pumps. A few lumped ion pumps at selected locations and turbo-molecular pumps for roughing are also part of the system. An average vacuum pressure with circulating beam of at least 10^{-9} mbar is foreseen and should provide beam lifetimes of 10-20 h. This ultra-low pressure and the small impedance of the designed beam chamber are providing the necessary high-current operation. The RF frequency is 500 MHz to utilize DESY cavities in the beginning of the operation of DELTA. Routine machine runs and first experiments are expected to start late in 1993.

PURPOSE OF THE DELTA FACILITY

The basic design goals of DELTA described above were chosen to provide a test-accelerator facility which also meets the stringent requirements necessary to serve as a powerful driver for different FEL experiments. Since test measurements and FEL operation of the storage ring imply rather frequent changes of machine optics, operational conditions and even beam-line modifications and have a severe influence on the beam qualities, DELTA will not be a typical light source for long-term experiments of Synchrotron-Radiation (**SR**) users and industrial production services. Although clearly available for preparation and test runs of such SR applications, the main purpose of DELTA is different. The intention of this test accelerator facility is threefold, namely :

(1) investigation of accelerator physics in general,
(2) FEL experiments from the visible to the XUV regime,
(3) Single-user experiments utilizing very special beam qualities.

Concerning point (1) an intense program of R & D of mode-damped single- and multi-cell cavities and an investigation of cavity modes and of the influence of higher-order-mode losses on beam quality are planned. The development of various accelerator components, SR instrumentation, feedback systems, beam-position and emittance monitors as well as of different insertion devices will also be performed. A special program for investigating the unsolved problems of low-energy injection and beam instability due to the generation of ions will be attacked, in particular, by using the booster.

Secondly, the main goal of DELTA is FEL research with the aim of pushing this technology from the visible regime to the XUV, in particular, to wavelength clearly below 20 nm. There is a three-phase FEL project planned at the DELTA laboratory for joint FEL-storage-ring operation [2,3]. Starting with an inexpensive and flexible optical klystron, **FELICITA I** , the main part of which is a simple electromagnetical undulator of 16 identical, 25 cm long periods (4m total length), the second step will be the 14 m long hybrid-magnet undulator, **FELICITA II** , of ≅230 periods of 6 cm length each.

In the beginning experiments with FELICITA I will be performed in the visible with the DELTA storage ring running at low energies (≅ 500 MeV). Since this device can simply be split into two undulators and a dispersive section by differently powering the various coils, FELICITA I can operate in an optical-klystron mode of about 10 % gain and lower output or in the normal FEL mode with lower gain (≅4%) and higher output. With a storage-ring energy of 1 GeV FELICITA I should reach the oscillator threshold also at intermediate wavelengths of the order of 100 nm, since at higher electron energies twice the peak current (180 A) is expected.

The next step is the high-gain FEL , FELICITA II , operating near 100 nm with DELTA running at 500 MeV and peak currents of 150 A. With the experience gained so far and operating DELTA at even larger peak currents and energies around 1 GeV, it should be possible to generate radiation at wavelength as low as 20 nm. This will be possible, however, only if suitable multi-layer mirrors of reasonably high reflectivity for these wavelength regime will then be available. If the severe mirror problems can not be solved in time, construction of a single-pass FEL with very high gain (750 periods of 2 cm length, few mm gap height) operating in a pulsed mode is envisaged as phase III of the Dortmund FEL development program.

Finally, the DELTA facility will also be available for short-term single-user research work either with the demand for testing their instrumentation or for very special beam qualities, like a particular time structure by single- or multi-bunch operation, high electron currents, optimized emittance and spectral brilliance, or particularly stable beams.

LATTICE AND MACHINE PARAMETERS OF STORAGE RING AND BOOSTER

Many features of the DELTA lattice and its optical functions are dictated by the requirement of using the storage ring as an efficient FEL driver. As mentioned already, these are

- low emittance
- short damping time
- high peak currents
- high flexibility of the optics
- long beam life time
- large energy acceptance
- high beam stability
- about 20 m long straight sections with zero dispersion and slowly varying betafunctions
- sophisticated accelerator-control and diagnostic system.

To fulfill all these conditions and, moreover, to provide sufficient space in between the many bending and focussing magnets, the original closely packed FODO lattice has been modified to a triplet structure. The fourfold symmetry has been preserved but with much more ample space between all magnets and a short straight section in each arc for injection and acceleration cavity, respectively. Different versions of the optics containing either the optical klystron, FELICITA I, in one of the long straight sections or a by-pass in the other one, have been calculated together with preliminary versions of two transfer channels for ejection of the electrons from the booster. A layout of the new lattice exhibiting all these features simultaneously is shown in Figure 1.

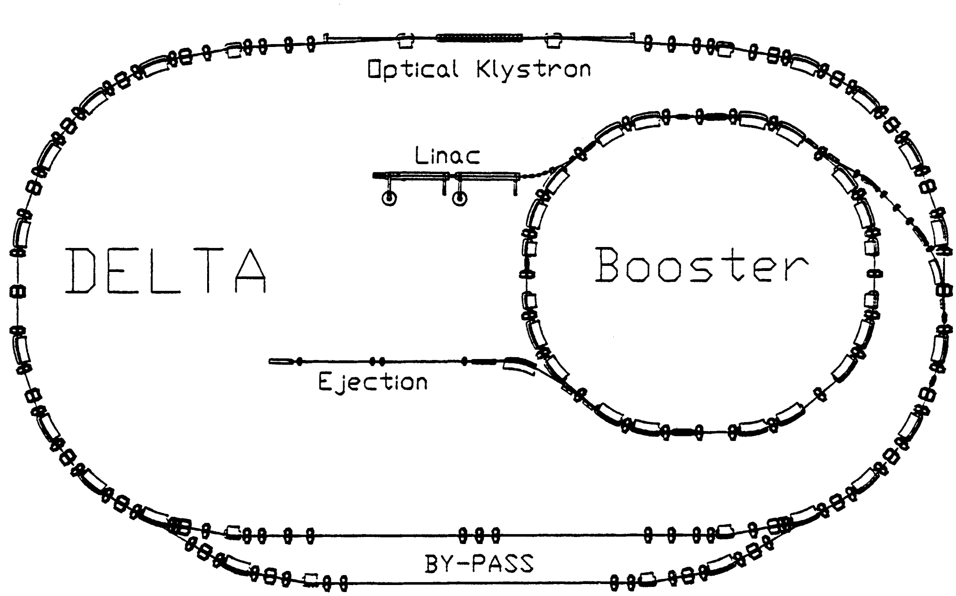

FIGURE 1 General layout of the lattices of the DELTA storage ring with optical klystron and by-pass (different version) and of the booster synchrotron BODO with two ejection lines and LINAC.

Figure 2 shows the dimensions of the new triplet focussing structure and the optical functions of the new lattice design for one full quadrant of DELTA together with the FELICITA I undulator as insertion in one of the straight sections. The unit cell has slightly been modified compared with the previous design [2]. Each cell consists now of two short (20 cm) defocussing and one long (40 cm) focussing quadrupoles mounted between two dipoles of 115 cm length, 20 ^{o} deflection angle, and 1.52 Tesla field strength at maximum energy of 1.5 GeV. Low emittance has been obtained, as for the original design, due to the relatively small and flat beta and dispersion functions. Dispersion matching with the long straight sections has been accomplished by splitting those four (of a total of 18) bending magnets adjacent to the drift sections into 8 bendings of half the length. In the case of the insertion of FELICITA I only 7° deflection instead of 10° are generated by the short matching dipoles. Another four quadrupoles are necessary at both sides of the long straight section to properly match the optical functions at the central symmetry point in the center of this drift section. By two additional weak 3° bendings the electron beam is deflected into the undulator and 10° deflection is obtained again. In this way, electron beam and laser beam are sufficiently separated near the mirrors in the optical cavity by ≅20 cm. Similar lattice calculations have been done with an extra by-pass at the opposite side of the ring, indicating the high flexibility of the DELTA optics. Chromaticity correction is made by sextupolar-field components integrated in the quads (2). Table 1 summarizes all parameters of the standard version of the linear beam optics of DELTA and the corresponding parameters of the booster BODO.

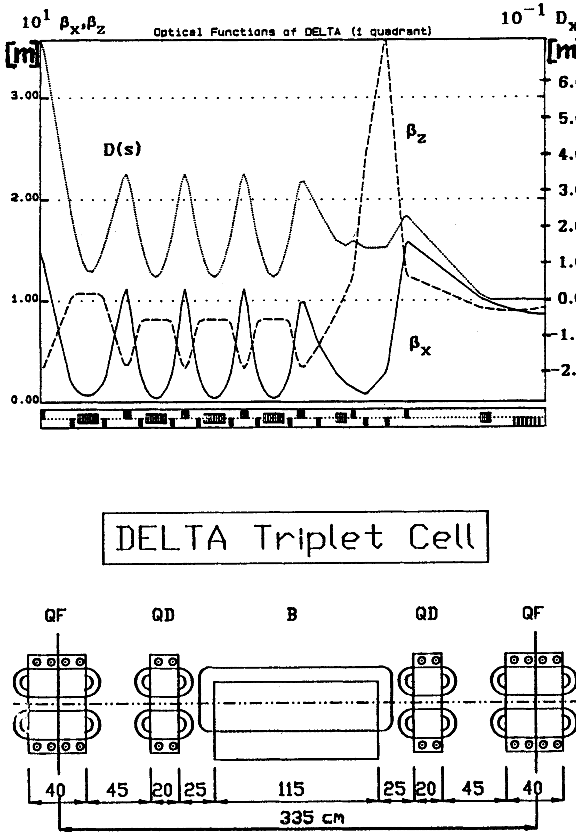

FIGURE 2 Dispersion D(s) (top) and horizontal and vertical beta functions $\beta_{x,z}(s)$ (middle) for one quadrant of DELTA and FELICITA I insertion included. – The lower part shows the layout of a single triplet cell.

The injection system of DELTA consists of a 100 MeV LINAC and the synchrotron BODO which can be ramped slowly to the full injection energy of DELTA of 1.5 GeV. Besides functioning as a standard synchrotron, BODO can also be operated in a storage-ring mode with low-energy current accumulation, but shorter life times. To reduce costs the same dipoles of 1.15 m length and the short 0.20 m quadrupole magnets as for DELTA are also used for BODO. The design of the various DELTA magnets was determined by the small cross-section of the vacuum chamber and the necessary field strengths and, therefore, also by arguments of cost reduction. The specifications

TABLE 1 MACHINE PARAMETERS OF (at 1.5 GeV) DELTA & BODO

			DELTA	BODO
Circumference	L	[m]	115.2	50.4
Number of Dipoles	n_d		22	20
short (0.575m)			6	4
long (1.15m)			16	16
Bending Radius	R_{bend}	[m]	3.43	3.43
Number of Quadrupoles	n_q		73	24
short (0.2m)			55	24
long (0.4m)			18	—
Tunes	Q_x		9.285	3.197
	Q_z		2.613	3.225
Natural Emittances:				
0% coupling	ϵ_x	[m·rad]	$1.1 \cdot 10^{-8}$	$3.8 \cdot 10^{-7}$
1% coupling	ϵ_x	[m·rad]	$1.1 \cdot 10^{-8}$	$3.8 \cdot 10^{-7}$
	ϵ_z	[m·rad]	$1.1 \cdot 10^{-10}$	$3.8 \cdot 10^{-9}$
100% coupling	$\epsilon_{x,z}$	[m·rad]	$0.55 \cdot 10^{-8}$	
Momentum Compaction	α		$4.48 \cdot 10^{-3}$	$9.0 \cdot 10^{-2}$
Natural Chromaticity	ξ_x		–20.95	–5.36
	ξ_z		–6.17	–5.43
Damping Times:				
horizontal	τ_x	[msec]	8.67	4.7
vertical	τ_z	[msec]	8.46	3.7
Synchotron Damping Time	τ_ϵ	[msec]	4.18	1.6
Revolution Frequency	f_R	[kHz]	2602.37	5952.38
Energy Spread	$\Delta E/E$		$7.02 \cdot 10^{-4}$	$6.7 \cdot 10^{-4}$
Energy Loss / Turn	ΔE	[keV]	136.24	136.0
Accelerating Frequency	f_{RF}	[MHz]	500	500
Harmonic Number	q		192	84
Max. Av. Current (1 bunch)	I_{max}	[mA]	100	
Max. Av. Current (10 bunches)	I_{max}	[mA]	500	
Number of Cavities	n_C		1	1
Rf Power for I = 500mA	R_{RF}	[kW]	80	60

of the bending magnets with 50 mm gap height and of the quadrupoles with 70 mm inner aperture were only slightly changed compared with the former ones (2). First designs of the accelerator hall (on ground level), laboratories and radiation-shielding walls were performed.

REFERENCES

(1) K. Wille, Nucl. Instr. Meth. Phys. Res. A272(1988)59; DELTA Report (1986) and Status Report (1988), University of Dortmund, unpublished.
(2) N. Marquardt, Proc. 1989 Particle Accelerator Conf., Chicago, to be published in IEEE Conf. Record.
(3) M. Negrazus, Contribution to this Conference.