DELTA, the Dortmund Electron Test Storage Ring Accelerator

J. Friedl
DELTA Group, University of Dortmund, FRG

Abstract

DELTA is a test facility for development of accelerator components and various FEL devices operating from visible to XUV regimes. The maximum electron energy is 1.5 GeV. The subjects to be investigated with DELTA are improvement of accelerator beam quality by developing mode-damped cavities, monitors, and undulator devices.

The present status of the accelerators (racetrack microtron, booster synchrotron and storage ring) and the first FEL experiment are described and the time schedule is given [1].

Introduction

The Dortmund ELectron Test Accelerator facility DELTA is funded since November 1989. It consists of a 100 MeV racetrack microtron, a full-energy booster synchrotron (BoDo) and a storage ring (SR-DELTA) with an energy variable from 500 MeV to $E_{max} = 1.5\ GeV$ (Fig. 1).

The storage ring is a "third generation light source". Its emittance is variable from $\epsilon(1GeV) = 4 \cdot 10^{-9}$ to $10^{-7}\ rad \cdot m$ (uncoupled) by changing the optics. The circumference is 115.2 m. Two arcs with triplet-cell structure are separated by two 20 m dispersion-free straight sections for experimental insertions. Various FEL's with wavelength from the visible to the XUV regime can be placed there as an experiment. Furthermore, investigations of mode-damped cavities, monitor development, and beam-quality improvement by feedback systems and special accelerator components are planned.

BoDo is designed as a ramped storage ring with FODO lattice. Special problems, like accumulation of high current and ion effects at low energies ($\leq 20\ MeV$), will be investigated.

The racetrack microtron with a 5 MeV injector is pulsed with a repetition rate of 100 Hz. Its output energy is stepwise variable between 20 MeV and 100 MeV (maximum) by a extraction magnet which can be mounted at different return paths.

Besides our own experimental program, DELTA should serve as a test facility for external groups using the storage ring for short-term single-user experiments utilizing very special beam qualities.

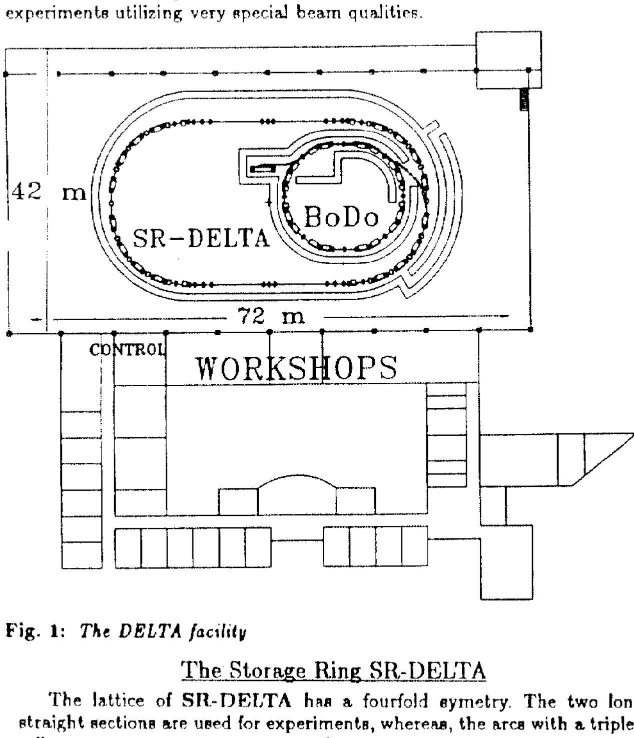

Fig. 1: *The DELTA facility*

The Storage Ring SR-DELTA

The lattice of SR-DELTA has a fourfold symetry. The two long, straight sections are used for experiments, whereas, the arcs with a triplet-cell magnet structure remain untouched. Fig. 2 shows the optical functions for operation of an optical klystron (FELTICITA I) installed in one of the experimental sections. The various optics guarantee zero dispersion in the straight sections. [2]

A list of machine paramèters is given in Tab. 1. To compensate the natural chromaticity 2-4 families of separate sextupole magnets are fixed at the yoke of the quadrupoles (Fig. 7). With correction to $\xi = +1$ the horizontal dynamic aperture is $\sigma_x = 37.5$ standard deviations at 1.5 GeV. The accelerating frequency is 500 MHz. For the start-up phase a one-cell DORIS-type cavity is foreseen.

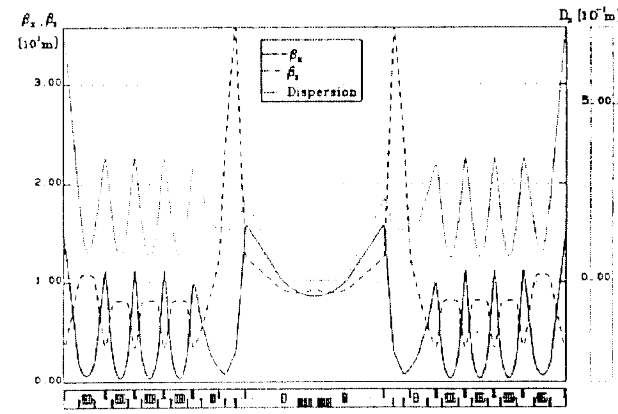

Fig. 2: *The optical functions of SR-DELTA operating with the optical klystron (one half of the ring).*

			SR-DELTA	BoDo
Circumference	L	[m]	115.2	60.4
Number of Dipoles	n_d		22	20
	long	1.10 m	16	16
	short	0.575 m	6	4
Bending Radius	R_{bend}	[m]	3.3	3.3
Number of Quadrupoles	n_q		73	24
	long	0.4 m	18	—
	short	0.2 m	55	24
Tunes	Q_x		9.285	3.197
	Q_z		2.613	3.226
Natural Emittances:				
0% coupling	ϵ_x	[m·rad]	$1.1 \cdot 10^{-8}$	$3.8 \cdot 10^{-7}$
100% coupling	$\epsilon_{x,z}$	[m·rad]	$0.6 \cdot 10^{-8}$	$1.90 \cdot 10^{-7}$
Momentum Compaction	α		$4.75 \cdot 10^{-3}$	$9.0 \cdot 10^{-3}$
Natural Chromaticity	ξ_x		-19.41	-5.36
	ξ_z		-6.49	-5.43
Damping Times:				
horizontal	τ_x	[msec]	8.66	4.75
vertical	τ_z	[msec]	8.45	3.71
Synchotron Damping Time	τ_s	[msec]	4.17	1.67
Revolution Frequency	f_R	[kHz]	2602.37	5948.26
Energy Spread	$\Delta E/E$		$7.00 \cdot 10^{-4}$	$6.72 \cdot 10^{-4}$
Energy Loss / Turn	ΔE	[keV]	136.48	136
Accelerating Frequency	f_{RF}	[MHz]	500	500
Harmonic Number	q		192	84
Number of Cavities	n_c		1 (1 cell)	1 (3-cell)
Rf Power	P_{CW}	[kW]	60	60

Tab. 1: *Parameters of* SR-DELTA *(optical-klystron operation) and* BoDo *for* 1.5 *GeV*.

The Booster Synchrotron BoDo

BoDo, the booster synchrotron, is designed as a ramped storage ring, to allow experiments on low energy injection and accumulation (from 20 to 100 MeV) and investigation of ion effects, respectively. The energy varies from 100 MeV (20 MeV) to 1.5 GeV. At a first stage BoDo is operated with a repetition rate of 1/5 Hz as preaccelerator for SR-DELTA. At a later time this will be raised to 3/2 Hz [3].

The lattice has a fourfold symetry for which the same magnets are used as for SR-DELTA. The optical functions are shown in Fig. 3 and the parameters are listed in Tab. 1. At 1.5 GeV BoDo has an emittance of $\epsilon = 3.8 \cdot 10^{-7}\ rad \cdot m$ (uncoupled). Because of the weak sextupole strength necessary for correcting the chromaticity ($m_{max} = 1.4\ 1/m^2$) sextupoles are integrated in the quadrupoles by additional coils. Using the same vacuum chamber as for SR-DELTA the dynamic aperture of BoDo is 14.7 standard deviations at 1.5 GeV. The RF system (Fig. 9) is the same as used for SR-DELTA but the accelerating structure is a 3-cell DESY-type cavity.

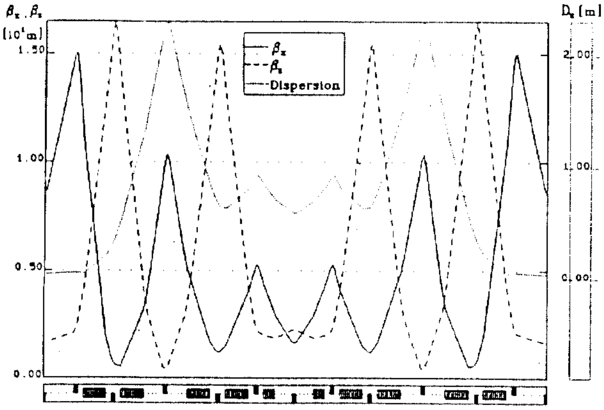

Fig. 3: *The optical functions of the booster synchrotron* BoDo *(one half of the ring).*

The Racetrack Microtron

For preaccelerating to an energy of $E_{max} = 100\ MeV$ a racetrack microtron with an injector LINAC section of 5 MeV is foreseen. It has 19 parallel return paths separated by 3.18 cm. The energy gain is 5 MeV per revolution by using of 3 GHz accelerating structure. The layout of the machine is shown in Fig. 4, the parameters are listed in Tab. 2.

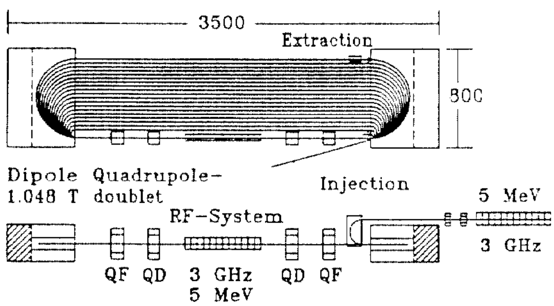

Fig. 4: *Layout of the racetrac microtron.*

Output Energy	E_{out}	[MeV]	100
1. Orbit Parameter	ν		1
2. Orbit Parameter	μ		50
Injection Energy	E_{in}	[MeV]	5
Total Number of Orbits			19
Magnetic Field Strength	B	[T]	1.048
Spacing between Orbits	d	[cm]	3.18
Diameter of First (Inner) Orbit	d_1	[cm]	6.37
Diameter of Last (outer) Orbit	d_{19}	[cm]	63.66
Total Orbit Length		[m]	112.16
Orbiting Time:			
First Orbit	t_1	[nsec]	16.68
Last Orbit	t_{19}	[nsec]	22.68
Total	t_{total}	[nsec]	374.08
Magnet Gap Width		[cm]	5
Distance between Magnets (effective field boundary)		[m]	2.4
Rf-System:			
Number of Klystrons			1
Structur-Type	Standing Wave	$\beta = 1$	π-Mode
Operating Wavelength	λ	[cm]	10
Energy Gain per Turn	ΔE	[MeV]	5
Emittance	ϵ	[π mm mrad]	~ 1

Tab. 2: *Parameters of the racetrack microtron .*

Control System

One goal of DELTA is the integration of an expert system into the control system to simplify machine handling. However, for first operation a modular control system will be available (Fig. 5). The level of display, shown in the upper line of Fig. 5, allows a status control of the machines and enables the operator to quickly change the various machine parameters. For these purposes OSF-MOTIV and InterView [4] is used. The level of control represents a database containing all informations of the machines. For the process level VME crates are used to control all devices of the field level via ARCNET or BITBUS. The three levels shown at the top of Fig. 5 are connected by an ETHERNET bus system.

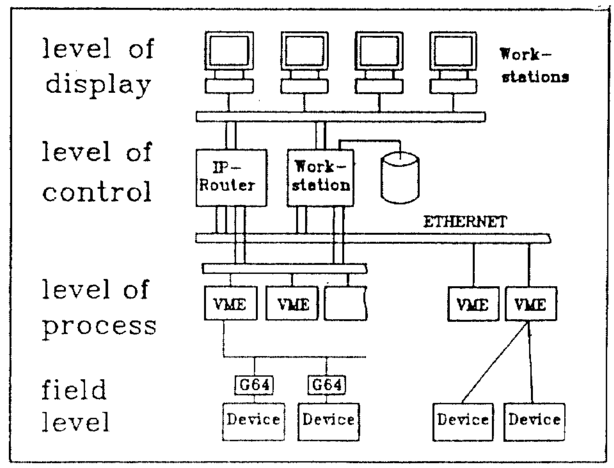

Fig. 5: *Block diagram of the* DELTA *control system.*

Monitors at DELTA

For the necessary control during operation the beam parameters are permanently measured by various monitors. For this aim, beam position (BPM) and intensity monitors are implemented, as well as pick-up elektrodes for determining betatron tunes and synchrotron frequency. The BPM's are of the 4-button pick-up type (Fig. 6) with a relative resolution of 10 μm and an absolute accuracy of better than 150 μm rms. By an electronic circuit (block diagram in Fig. 6) the signals of the four buttons are amplified sequently but only the 500 MHz component is used to get the position information. For the intensity measurement two types of monitors are installed in SR-DELTA and BoDo. One measures the DC component of the electron beam only, whereas the other is used for fast single-bunch detection. For this purpose the monitor developed by K. Unser [5] is implemented. The tunes and synchrotron frequency are measured by using BPM-type pick-ups after exciting transverse and longitudinale beam oscillations [6].

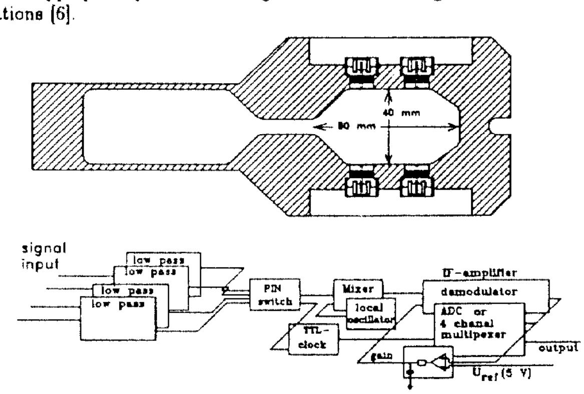

Fig. 6: *Beam position monitor with block diagram of the electric circuit.*

Magnets of SR-DELTA and BoDo

For **SR-DELTA** and BoDo magnets of identical design are used (Fig. 7). Straight dipoles are constructed with a length of 1.10 m, a gap height of 5 cm and a gap width of 24 cm. The magnetic field is 1.52 T at 1.5 GeV. For this field the current of the magnets is 995 A at 17 V (64 windings). The quadrupoles of 20 cm and 40 cm length have a pole radius of 35 mm and coils with 188 windings. For maximum excitation the current is 57 A at 26 V and 37 V, respectively.

Vacuum System of SR-DELTA and BoDo

The stainless-steel vacuum chambers of **SR-DELTA** and **BoDo** have an antechamber at the inner side of the rings for installing integrated pumps (Fig. 8). In **SR-DELTA** non-evaporable getter pumps (NEG) and distributed ion getter pumps (DIP) are implemented, whereas in **BoDo**, distributed NEG pumps and separate ion getter pumps are foreseen. To obtain the operating pressure of these pumps ($10^{-5}\ Pa$) movable turbo molecular pumping units are used sector-wise. With this concept an absolute pressure of $10^{-7}\ Pa$ can be reached at operation with maximum beam current, which is neccessary to achieve beam lifetimes of the order of 10 houres.

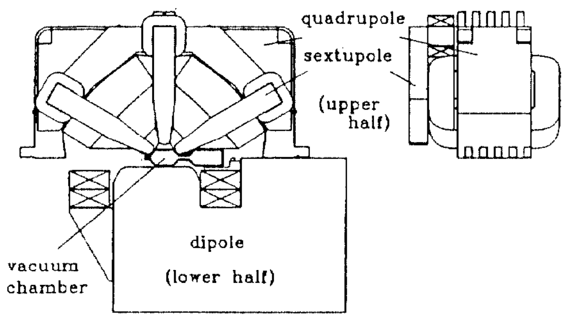

Fig. 7: *Combined view of dipole, quadrupole, and sextupole with vacuum chamber in place.*

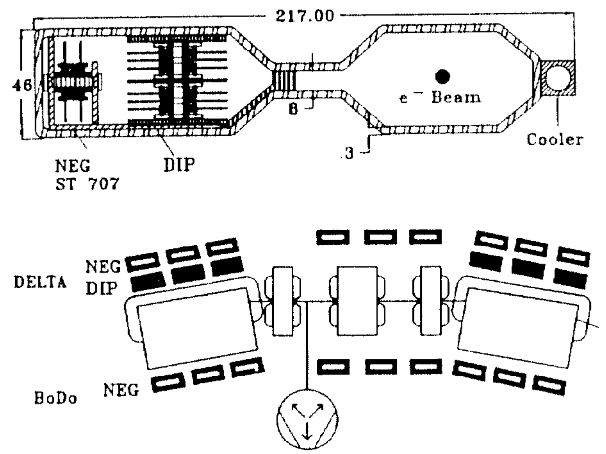

Fig. 8: *Vacuum-chamber cross section and ditribution of pumps for* SR-DELTA *and* BoDo*, respectively.*

RF System

The accelerating frequency for **SR-DELTA** and **BoDo** is 500 MHz. For both machines the same type of klystron with $P_{CW} = 60\ kW$ is used. To save costs for installing circulators, we might use electronic switches in order to avoid damage of klystrons by power reflection. A block diagram of the RF system is given in Fig. 9.

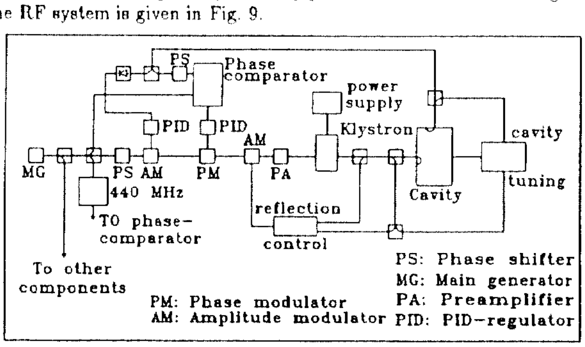

Fig. 9: *The RF system of* SR-DELTA *or* BoDo.

The First FEL Experiment FELICITA I

To study the behaviour of **SR-DELTA** with FEL operation and to get experience, a first experiment, **FELICITA I**, is under construction (Fig. 10). Its main part consists of a 4 m long, electromagnetic undulator with 16 periods of 25 cm length each. **FELICITA I** can be operated with high gain and low-output power as an optical klystron (for which only 7 periods are used) and with low gain and high-output power in a FEL mode (using all periods equally powered) (Tab. 3) [7]. Depending on storage-ring energy the resonant wavelength is 418 nm at 500 MeV and 104 nm at 1 GeV, respectively. In a later stage of development **SR-DELTA** shall drive a 14 m long permanent magnet undulator with gain values of 3-5 in the wavelength regime below 100 nm (**FELICITA II**) [7].

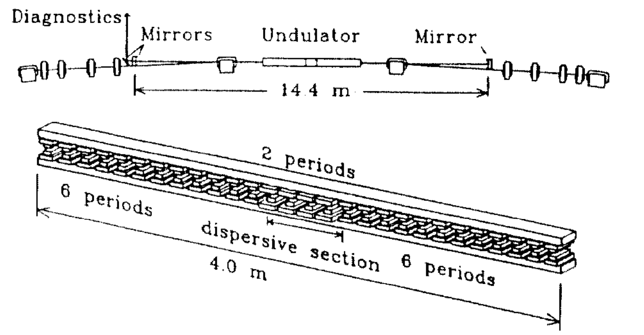

Fig. 10: *The first FEL experiment,* **FELICITA I**, *inserted in one of the straight sections of* **SR-DELTA**.

UNDULATOR			OK MODE		FEL MODE	
Period Length	L_u	[m]	0.25		0.25	
Mag. Peak Field	B_u	[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		/	
DATA OF THE OPTICAL CAVITY						
Length	L_r	[m]	14.4		14.4	
Central Beam Waist	w_o	[mm]	0.39		0.39	
Mirror Curvature Radius	R_m	[m]	7.38		7.38	
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 (4 bunches)	I	[mA]	120	240	120	240
Peak Current	$\hat{I}$	[A]	90	180	90	180
Max. Gain	G_{max}	[%]	10.4	10.3	4.0	3.9
Gain / Peak Current	$G/\hat{I}$	[10^{-4}]	11.6	5.7	4.6	2.2
Average Output Power	P_{out}	[W]	0.28	8.9	1.65	52.8

Tab. 3: *Parameters for* **FELICITA I** *for FEL and optical-klystron operation and expected data (worst case estimates).*

Time Schedule

Construction of the buildings will start at the end of the year. It will be ready for installation of the accelerators in autumn 1991. The different machines will be built up in parallel. The microtron is expected to go into operation at the end of 1992. In July 1993 BoDo will be finished and the total facility enters the test phase at the end of 1993.

Conclusion

The storage-ring project **DELTA** has overcome most of the planning phase and hardware quotations are asked for. Therefore, a status report is under preparation which gives more detailed information. [1]

References

[1] DELTA Group; Status Report; in preparation.

[2] D. Schirmer, DELTA; Entwicklung von Strahloptiken für den Testspeicherring DELTA auf Basis der Triplett-Struktur; Diploma Thesis 1989.

[3] W. Bothe, DELTA; Magnet Circuits for DELTA; presented at this conference.

[4] A. Lipton et al.; Composing User Interfaces with InterViews; IEEE Software 1989.

[5] K. Unser, CERN; Design and Preliminary Tests of a BEAM Intensity Monitor for LEP; CERN/LEP-BI/89-07.

[6] U. Oeftiger, DELTA; Entwicklung eines Verfahrens zur Bestimmung des Arbeitspunktes für Teilchenbeschleuniger; Diploma Thesis 1990.

[7] F. Brinker et al.; DELTA, a New Storage-Ring FEL Facility at the University of Dortmund; to be published in Nucl. Instr. and Meth.