ICFA 17TH ADVANCED BEAM DYNAMICS WORKSHOP ON
FUTURE LIGHT SOURCES

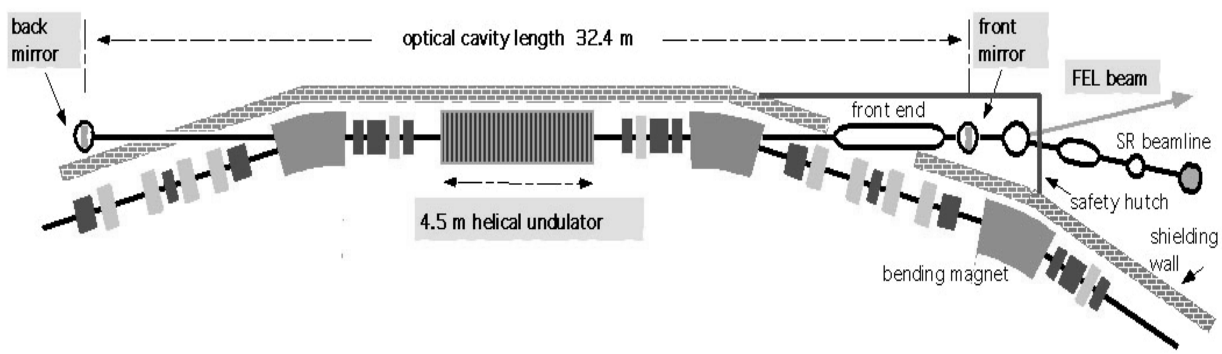
Development of a Combined Synchrotron Radiation and VUV Free-Electron Laser Facility

M. Poole, Daresbury Laboratory

APRIL 6-9, 1999
ARGONNE NATIONAL LABORATORY, ARGONNE, IL U.S.A.

Contract No. FMGE-CT98-0102

Development of a Combined Synchrotron Radiation and VUV Free-Electron Laser Facility



Partners :

- Sincrotrone Trieste (Italy) (coordinator)
- CEA/LURE (France)
- CLRC-Daresbury Laboratory (England)
- Univ. Dortmund, DELTA Project (Germany)
- ENEA-Frascati (Italy)
- MAX-lab (Sweden)

Project Start : May 1st 1998
Project Duration : 3 years

Europe's first "third generation" high-brightness synchrotron radiation facility for the VUV/Soft-Xray region.

First user operation in 1994; presently 10 operational beamlines; 6 insertion devices; • 5000 h user operation/yr.

Circumference	**259.2 m**
Number of ID straights	**11**
ID length	**4.6 m**
Injection/Operating Energy	**1GeV / 2 GeV**
Beam current - multibunch **- single bunch**	**350 mA** **~ 50 mA**
Emittance - horizontal **- vertical**	**$7\ 10^{-9}$ m rad** **$\sim 1\ 10^{-10}$ m rad**
Energy spread	**$8.0\ 10^{-4}$**

Main Objectives of the ELETTRA FEL Development Project :

- Demonstrate operation of a Free-Electron Laser (FEL) on ELETTRA, providing a highly monochromatic, intense, tuneable, coherent source of UV/VUV radiation in the range 350 nm to below 200 nm

- Demonstrate its suitability as a source for experiments, by itself and in synchronism with synchrotron radiation

- Demonstrate compatibility with ‘normal’ SR operation (lower energy and current, but still useful for certain experiments, particularly time resolved experiments)

Main Novel Technical Features

- Use of a **Helical undulator (optical klystron)** to reduce power loading and hence mirror degradation

- Sophisticated **Mirror chambers**
  - in-situ exchange between 3 mirrors to maximise use of limited commissioning time, and to cover a wider operating wavelength range
  - specially designed mirror holders to reduce mirror distortion

- Use of a **high quality, high energy electron beam** :
  - higher gain allows the possibility of exploring other mirror types
  - higher ring energy provides higher output power

Project Status :

- Overall layout defined, including implementation in ELETTRA and optical cavity parameters

- Beamline front-end and back-ends defined; front-end construction started in-house

- Vacuum chamber modifications under study

- Mirror chamber design complete; under tender for main components

- Mirror holder mechanism defined; simulations of power loading carried out

- Undulator parameters defined; mechanical support systems and permanent magnets ordered; magnet holders being designed

- Modulator magnet (for optical klystron) designed and under tender

- Initial measurements of electron beam performance carried out, and will continue with newly commissioned dual-sweep streak camera

- Theoretical studies of FEL performance have been carried out and are continuing

2. Choice of Main Parameters

i/ Wavelength

First operation at 350 nm (present SuperACO operating wavelength) followed by :

- 300 nm (under development at SuperACO)
- 250 nm (DELTA 2nd phase)
- 200 nm ... 155 nm

ii/ Energy

Initial operation at 1 GeV for convenience (normal injection energy) and a good compromise :

Lower energy means :

+ higher gain, less power loading

- worse beam stability and lifetime

- less useful for SR experiments

Future operation at 1.3-1.5 GeV for :

- increased FEL power
- increased compatibility with SR users

iii/ Undulator

The undulator will also be used as a source of synchrotron radiation for a microscope beamline using both linear and circular polarization in the 30 eV – 1 keV range (at 2 GeV).

- **FEL operation:**

A short period maximises gain (increased N) but reduces scope for increase in operating energy.

- **SR operation:**

A short period improves flux at 1 keV but causes power density problems at 30 eV.

Optimum period length for both applications = 100 mm

$\Rightarrow$ K_{max} • 5.1 for 350 nm at 1 GeV

Final design will have a higher field strength (K = 6.2-6.6) to allow the possibility of going to higher ring energy operation:

- 350 nm possible at up to 1.2-1.3 GeV
- 300 nm possible at up to 1.3-1.4 GeV
- 250 nm possible at up to 1.4-1.5 GeV

Optical klystron configuration:

- higher gain and output power
- flexibility (e.g. linear polarization on a single harmonic using crossed circularly polarized devices)
- permits two standard 2.0 m undulator units to be used with separate modulator

iv/ Optical cavity

Possible lengths which are synchronised with ELETTRA :

Cavity length (m)	# bunches
21.6	6
32.4	4
43.2	3

Choose shortest length that allows both mirror chambers to be installed outside the ring tunnel : 32.4 m

Cavity parameters:

Length	**32.4 m**
Mirror to centre ID distances	**17.7 m, 14.7 m**
Position of waist	**centre of undulator**
Rayleigh length	**4 m**
Mirror radii	**18.6 m, 15.8 m**
Stability parameter (g_1g_2)	**0.78**
Waist size (*w*, 350 nm)	**0.67 mm**

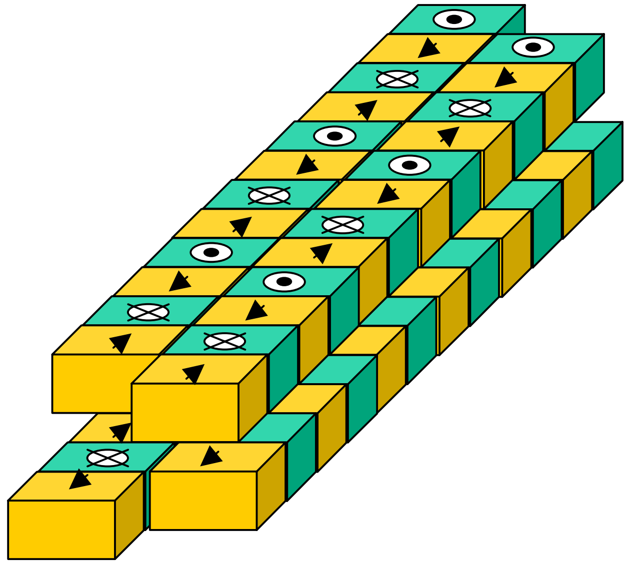
3. Mirror Chambers

Main features:

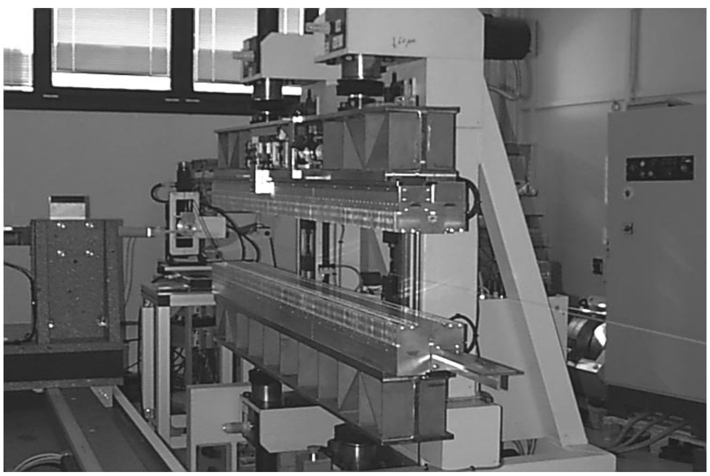
- very stable ‘synthetic granite’ support block
- 3 remotely interchangeable mirrors
  + straight through direction for spontaneous SR
- up to 40 mm diameter mirrors
- 3 external motorized motions X, Y, Z
- 3 internal UHV-compatible motorized motions
  pitch, yaw (coarse + fine) and mirror translation
- provision for future addition of water cooling
- possibility to remove and replace mirrors without breaking the mirror chamber vacuum using ‘load-lock’ system

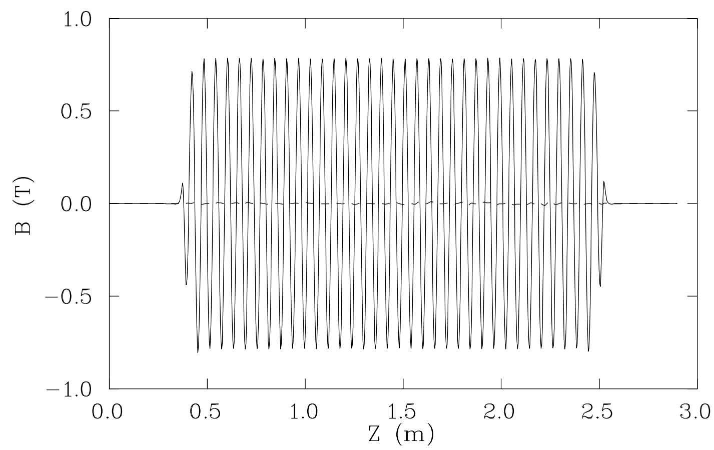
4. Undulator

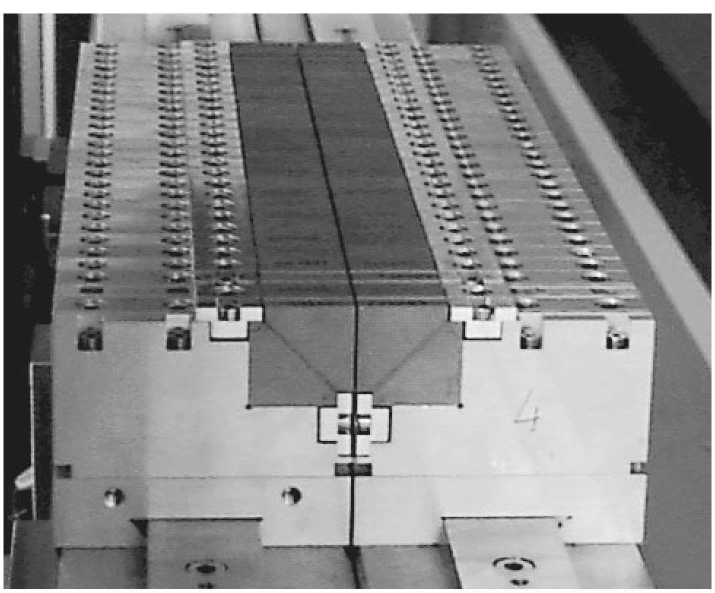
➢ Sasaki APPLE-2
structure will be used :

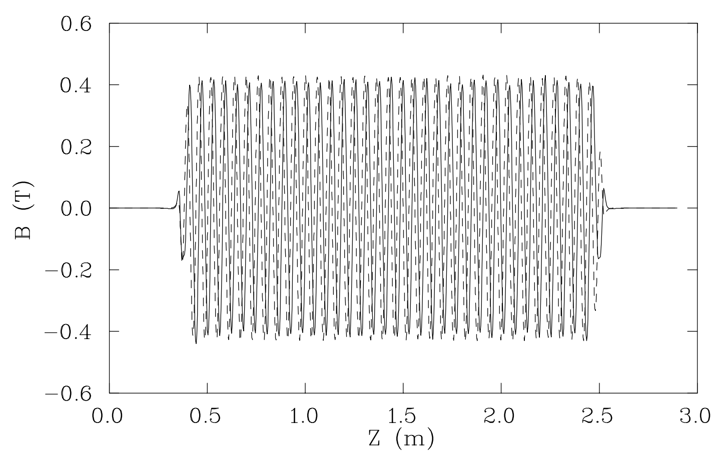


➢ similar 2.1 m device already constructed (EU6.0) :









Measured magnetic fields
in the linear (upper) and circular (lower)
polarization modes.

5. Electron Beam Performance

Main parameters:

Energy	1 GeV	
No. bunches	4	
Max. current	~ 100 mA	
Natural rms emittance	1.74 nm rad	
Natural rms energy spread	0.04 %	
Natural rms bunch length	6.3 ps	
Current/bunch	10 mA	20 mA
Measured bunch length	25 ps	30 ps
Expected energy spread	0.16 %	0.19 %
Corresponding peak current	140 A	230 A

Lifetime : ~ 1.5 h at 100 mA
consistent with calculated Touschek lifetime assuming measured bunch length, and reasonable x 2 emittance increase due to IBS and 3 % coupling.

Stability : analysis of pick-up signals shows rms longitudinal motion < 0.5 deg. of r.f. phase, i.e. < 3 ps. Transverse stability also good.

Future measurements:

- Further measurements of bunch length and beam stability using a new dual-sweep streak camera
- Measurements of energy spread
- Adjust coupling factor/vertical dispersion to increase beam lifetime

6. FEL Performance

Gain

Small signal gain per pass for TEM_{00} mode,
20 mA/bunch, 350 nm, helical mode:

- standard undulator **Gain ~ 40 %**
- optical klystron with optimized $N_d \sim N$ **Gain ~ 60 %**

(with previously measured bunch lengths)

Power

Latest simulations (Dattoli et al.) including bunch length increase due to laser action predict maximum output power of **~ 1 W**

Ignoring the bunch length increase gives **~ 3 W**

Pulse length

Simple theory predicts a narrowing factor of ~ 60
at the Fourier limit :

laser pulse length	30 ps $\rightarrow$ 0.5 ps
linewidth	1.2% $\rightarrow$ 2 10^{-4}

We can therefore reasonably expect :

laser pulse length	**~ few ps**
linewidth	**~ 5-10 10^{-4}**

3 W @ 3ps rms $\Rightarrow$ **86 kW peak power**, **0.65 µJ pulse**

Power Loading Problems *(work done by B. Fell, Daresbury)*

Spontaneous Emission

Power on 40 mm diameter mirror at 14.7 m :

A) 350 nm, 1 GeV, 100 mA	**0.6 W**
B) 200 nm, 1 GeV, 100 mA	**4.0 W**
C) 200 nm, 1 GeV, 100 mA	**5.9 W**

without any cooling – case B – 230 ^{o}C
$\Rightarrow$ need for cooling

- bare surface mirror to mirror holder contact – high forces required for good thermal contact will lead to significant distortion
- propose use of medium (InGa) between them to improve thermal contact, plus light retaining springs

Laser power

mode size (w) = 2.54 mm (350 nm), 1.92 mm (200 nm)
(1.3 mm assumed in calculations)

$\rightarrow$ mirror temperature rise : 15 ^{o}C per W
$\rightarrow$ significant slope errors, even for 1 W absorbed power

- ➢ What is the criterion for acceptibility for distortion ?
- ➢ Will the laser power be limited by thermal distortion of the mirrors ?
- ➢ What alternatives can be considered ?

Updated comparison of expected performance with SuperACO FEL:

	ELETTRA	SuperACO
Ring energy (FEL mode)	1.0 GeV	0.8 GeV
Gain (max)	40-60 %	2 %
Wavelength range	350 - < 200 nm	350-363 nm
Repetition rate	4.6 MHz	8.1 MHz
Pulse length (FWHM)	~ 7 ps	~ 50 ps
Peak power (max)	90 kW	0.7 kW
Pulse energy (max)	0.7 µJ	0.04 µJ
Average power (max)	3 W	0.3 W
Photon flux† (max)	$2\ 10^{18}$	$2\ 10^{17}$
Polarization	linear, circular	linear

† photons/s within the laser bandwidth

7. Programme

- Construction of all main components: Jan.-Jul. '99

- Installation: Aug./Sep. shutdowns '99

- Optical Cavity installation: Oct. '99

- Start FEL commissioning: 23rd Oct. '99

- First lasing at 350 nm: before the end of '99 ??!

- End of contract: end April 2001
  - lasing over a wide wavelength range
  - lasing below 200 nm
  - laser operation in parallel with SR utilization
  - pilot FEL experiments performed

- Towards the end of this period, depending on the results obtained, and the user interest, the setting up of a UV/VUV FEL User Facility will be considered.