ELETTRA Status Report

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Abstract

ELETTRA, is the Italian Third Generation Light Source built at Trieste. The electron storage ring operates in the energy range of 1.1-2 GeV and is optimized for the emission of light in the VUV - Soft X-Ray range. Commissioning of ELETTRA was started in October 1993. In the present stage about 40% of the operations time is dedicated to the commissioning of the four beamlines installed up to now and to scientific experiments. Besides the technical description of the facility, the first commissioning results and its present performance are presented.

1. INTRODUCTION AND OVERVIEW

The company Sincrotrone Trieste was founded in November 1986 with the aim of providing Italy with a dedicated third generation synchrotron radiation laboratory. After having defined the characteristics of the machine in a users workshop in July 1987 [1], C.Rubbia, as the president of the company assembled a first small group of accelerator experts who presented a first version of the Conceptual Design in mid 1988 to the Board of Directors [2]. The construction of the main building started in July 1991 and in October 1993 the first beam could be stored in ELETTRA. Figure 1 shows an aerial view of the ELETTRA facility. The main parameters are listed in table 1.

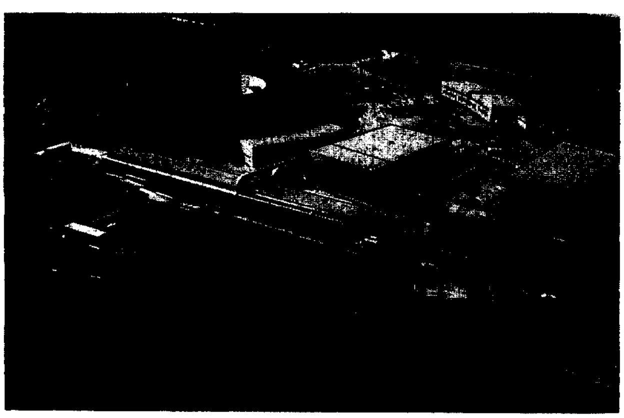

Figure 1. Aerial view of the ELETTRA facility

1.1 Present performance

Injection is performed from a high energy linac [3] which in the present state has been commissioned up to an energy of 1.25 GeV. During normal operation the linac is working at 1.1 GeV in order to increase its reliability. A ramping procedure was installed which allows the selection of any operating energy from injection up to the maximum energy of 2.3 GeV [4]. Currently, the experimental runs are performed at 2 GeV, with three insertion devices closed to a minimum gap of 26 to 28 mm [5]. In the multibunch mode a maximum current of 530 mA has been reached, whereas >50 mA have been stored in a single bunch, both at an energy of 1.1 GeV. The lifetime at 1.1 GeV has a strong contribution from Touschek scattering. After 60 hours of accumulated dose, the yield is reduced to about 2-4 10^{-6} mol/photon at 1.1 GeV. At 2 GeV, beam gas scattering dominates the lifetime due to the stronger radiation desorption and outgasing effects due to the increased thermal load.

Table 1
ELETTRA Main Parameters

Magnet structure		DBA
Nominal energy range, GeV		1.1 - 2.0
Circumference, m		259.2
Harmonic number		432
Emittance (1.5 GeV), πrad-m		4 10^{-9}
Momentum spread (1.5 GeV)		6 10^{-3}
Tunes	Q_H	14.3
	Q_V	8.2
Natural chromaticities	ξ_H	-42.0
	ξ_V	-14.0
Momentum compaction		1.6 10^{-3}

2. TECHNICAL DESCRIPTION

2.1 Lattice and Magnet Structure

The lattice is built up as an extended Double Bend Achromat structure with a twelve fold symmetry. There are two focusing and one central defocusing quadrupole in the dispersive section and triplet focusing in the insertion device straights to allow for some flexibility in matching the beta functions there.

The 24 bending magnets have a magnetic length of 1.44 m and a field of 1.2 Tesla at 2 GeV. They are of the combined function type with a modest field index of n=13 in order to enhance the horizontal damping partition number, and consequently further reduce the emittance and to avoid excessive growth of the vertical beta function over the bending magnet, where the beam is focused strongly in the horizontal plane.

Nine quadrupoles per achromat, 108 in total, are used to focus the beam in both planes. Since they have to be open in the horizontal plane for light extraction, the yokes are split in an upper and a lower half which are clamped together by a C-shaped support plate of stainless steel. The maximum gradient is 20 T/m.

Two sextupole families, with two elements per plane and achromat are used to compensate the chromaticities. An additional family with 2 sextupoles per achromat is placed in the dispersion free region in order to reduce geometric and chromatic aberrations. In total there are 72 sextupoles with a maximum double gradient of 365 T/m^2.

For orbit correction, 82 dipole steerers have been implemented, which are U-shaped with an opening to the lower side. This allows the installation of a sputter ion pump from below and therefore helps to resolve space problems.

A view of the storage ring magnet structure is given in figure 2.

Figure 2. Storage ring magnet structure

2.3 Vacuum

The stainless steel vacuum chamber [6] has a rhomboidal cross section which is kept constant around the ring, except in the insertion device straights where a smooth taper reduzes the vertical size to a small gap. In the bending magnets the chamber is connected via a 1 cm slot to a local antechamber with reinforced pumping where 80% of the radiation is intercepted by water-cooled copper absorbers. The vacuum chamber is equipped with a microprocessor controlled bake-out system. Sputter ion pumps are used as the principal pumping devices. Only in the bending magnets is the pumping enhanced by NEG strips. Movable turbomolecular pumps are taken to generate the pre-vacuum and are used during in-situ bake-out. Figure 3 shows as a preliminary result the improvement of the estimated yield for the ELETTRA vacuum system with the accumulated dose.

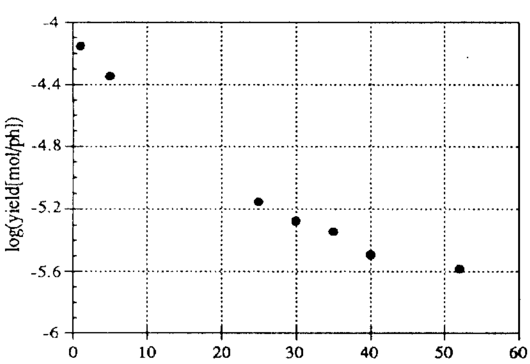

Figure 3. Yield as a function of accumulated dose

2.3 Radio Frequency

The 500 MHz RF-system is composed of four power plants of 60 kW each [7]. The stations are connected with a coaxial line via a circulator to four independent cavities which are installed in the dispersive sections of the achromats. A local cooling/heating station maintains the cavity operating temperature constant at 55° with a precision of 0.1°. The copper cavity, made by computer controlled high precision machining, is tuned by deformation, acting on the necks of the cavity. For reactive compensation of beam loading a maximum shift of 80 kHz in frequency is needed, which is reached by 0.1 mm deformation, well within the elastic limit. All cavities are equipped with an amplitude loop and phase loop.

2.5 Injection

The high energy linac uses a SLED system for energy doubling, with a maximum energy amplification factor of 2.3. In this way 200 MeV acceleration is generated in a 6.2 m long structure.

A maximum gradient of 29 MeV/m has been reached so far with a pulse length of 3-3.5 µs and a klystron power of 40 MW.

From the exit of the linac the beam is transferred via an underground transfer line to the inner part of the storage ring, deflected upwards and then injected horizontally from the inner side into the storage ring [8]. Two septa in a common vacuum tank connect the transfer line with the storage ring. One straight section of the achromat structure is used to accommodate the septum and four storage ring injection kickers.

2.6 Instrumentation

The storage ring instrumentation comprises 96 beam position monitors (BPM), 6 fluorescent screens, 3 scrapers, 1 tune measurement system and 1 synchrotron light profile monitor [9]. A BPM is made up as a single block with four button pick ups, which is flanged by two VAT-seal flanges to the vacuum chamber. Each block has two tooling balls, which allow a precise calibration of the mechanical BPM position after installation in the ring. All BPMs are transversely attached to the adjacent quadrupole, but free to move longitudinally.

2.7 Controls system

The ELETTRA control system is based on a distributed architecture of 3 computer layers connected by two networks [10]. The upper level network which connects the computers in the control room with the local process computers (LPC), is based on Ethernet and the TCP/IP protocol family. The connection between the LPCs and the microprocessor EIUs on the field is provided by a multidrop highway, MIL1553B. Both LPC and EIU are based on the Motorola 680x0 family and the VME bus standard. OS/9 was chosen as the real time operating system. Powerful Unix workstations are used in the control room and graphical user interfaces allow an easy operation of the machine.

2.8 Insertion Devices

The free length between two quadrupoles in the straight section is 6.2 m, of which 4.8m is available for insertion devices [11]. The remaining space is used for bellows, valves, correctors, tapers and vacuum pumps. Each insertion device is composed of 3 independent modules of 1.5 m length. A pure permanent magnet solution of NeFeB was chosen for undulators, whereas a hybrid structure was adopted for the wiggler.

The main parameters of the insertion devices approved by the Program Advisory Committee, and their status are listed in table 2.

Table 2
ELETTRA Insertion Devices

ID - type	N	Gap[mm]	Bo[T]	K	Status
U12.5	36	28	0.506	5.91	operat.
U5.6	81	27	0.444	2.34	operat.
W14.0	30	26 (20)	1.3 (1.6)	17	operat. +)
U8.0	19	20	0.866	6.5	constr.
U12.5	36	28	0.506	5.91	constr.
EEW	12	25	0.6 (v) 0.047 (h)	13 1	design

+) in parenthesis the numbers for the new 20 mm chamber

All devices are equipped with an interlock system in order to avoid damage of the vacuum chamber through missteering of the photon beam. Compensation coils are attached to the undulators, which are used to dynamically correct residual dipole distortions of the device during gap variation. Excellent performance of the devices was reached by optimizing the positioning of the individual blocks by simulated annealing. In addition, shimming techniques were used to further improve the spectrum quality and to reduce adverse effects of the devices on the electron beam.

Table 3
Milestones of ELETTRA Commissioning

Date	Achievement
Oct. 4 /1993	Start of commissioning
Oct. 6	2000 turns
Oct. 8	Stored beam
Oct. 16	216 mA
Oct. 25	Bending magnet experiment
Nov. 7	Radiation seen from U5.6
Dec. 11	410 mA
Jan. 24 /1994	2.3 GeV
Feb. 4	Experiment at 1.5 GeV
Mar. 9	Light from U5.6 with low gap

3. COMMISSIONING AND ACCELERATOR PHYSICS ISSUES

The commissioning of ELETTRA started on October 4 and has progressed without major problems [5]. On the third day, beam was stored for the first time and in the following days the current level was increased up to 216 mA on October 16. A proof of principle experiment using bending magnet synchrotron radiation could already be carried out on October 25. Table 3 summarizes the the major commissioning milestones.

3.1 Optics, closed orbit

The machine model based on the magnetic measurements is in good agreement with global parameters measured on the machine, such as tunes, beta functions and chromaticities. Orbit correction has been performed down to rms values of 0.13 mm horizontal and 0.11 mm vertical [12]. The residual dispersion error is about 4 cm for a well corrected orbit, and shows predominately the fundamental harmonic. The optical asymmetry for a well corrected orbit is 10% in the vertical plane and 15% in the horizontal plane [13].

The horizontal emittance has been verified by measuring the beam size with the synchrotron radiation profile monitor and roughly confirmed by fitting the radiation spectrum measured with the U5.6 undulator.

Coupling of the emittance to the vertical plane is caused by skew quadrupole errors and spurious vertical dispersion. The emittance ratio due to skew quadrupole effects has been measured by registering the tunes when the coupling resonance is crossed. A value of 0.6% at the nominal working points (14.3, 8.2) could be found in this way, without taking any additional measures apart from an orbit correction to rms values less than 0.15 mm in both planes [5].

The residual vertical dispersion error generates an emittance coupling of 3-5%. This effect is intentionally used to store higher currents at the injection energy of 1.1 GeV. At the operations energy of 2 GeV, the vertical dispersion will then be corrected down to the mm level.

3.2 Nonlinear effects

One of the great concerns for 3rd Generation Light Sources in the low energy range, was the reduction in dynamic aperture caused by intrinsic nonlinearities of insertion devices. Dynamic aperture measurements performed on ELETTRA at low energy (1.1 GeV, in order to enhance the insertion device effects) revealed that the results from simulations are somewhat pessimistic.

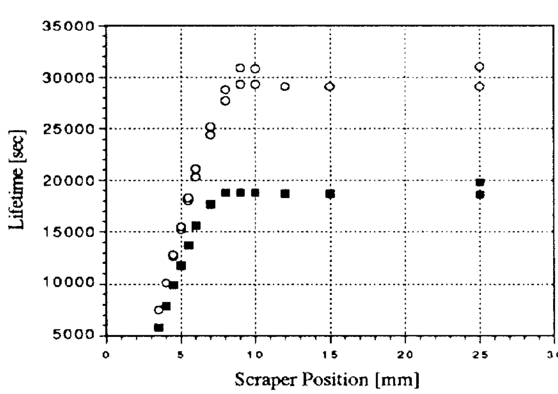

Figure 5. Lifetime at 1.1 GeV versus scraper position with insertion devices open (circles) and closed (squares)

Due to the already small gap of the ID vacuum chamber, the lifetime is dominated by elastic beam gas scattering. From the comparison of the two measurements we find a reduction of 1 mm if all three insertion devices presently installed in ELETTRA, are closed to their minimum gap. At 2 GeV however, no effect has been seen from insertion devices

3.3 Beam Lifetime

The lifetime has been measured under various conditions. At low energy were the yield after accumulation of 60 Ahrs is reduced to about 2-4 10^{-6} [mol/photon], the lifetime is strongly affected by Touschek scattering. At high energies the desorption is increased, predominately to thermal effects and the lifetime is limited by elastic beam gas scattering. Figure 6 shows the inverse lifetime as a function of beam current, for 1.1 GeV and 2 GeV [14].

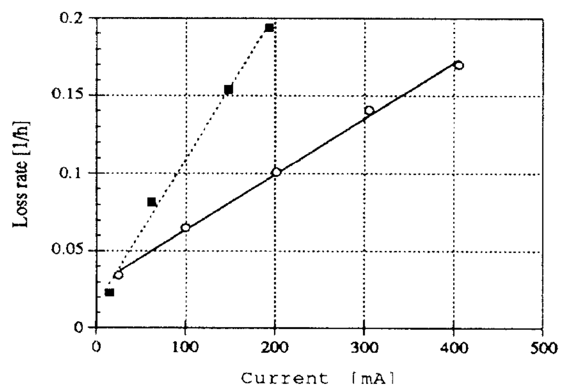

Figure 6. Lifetime versus current for 1.1 GeV (circles) and 2 GeV (squares)

3.5 Multibunch instabilities

Longitudinal multibunch effects are visible even at very low currents, as predicted by theory. In ELETTRA dangerous parasitic cavity modes are avoided by changing the operating temperature of the cavities [7]. Figure 7 for example shows how the most relevant longitudinal mode frequencies of cavity #3 vary as a function of cavity temperature.

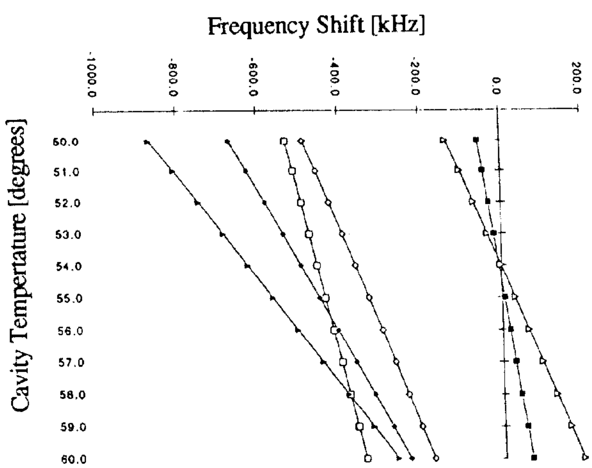

Figure 7. Parasitic cavity modes as a function of temperature

Transverse multibunch instabilities are observed as spontaneous betatron sidebands with synchrotron satellites and sudden beam losses. They are seen only when the cavity temperature is tuned close to a resonance of a parasitic cavity mode with a coupled bunch mode. So far no problems with transverse coupled bunch modes have been encountered.

3.6 Single bunch instabilities, broad band impedance

Several measurements at 1.1 GeV were performed in order to evaluate single bunch effects and the broad band impedances [15]:

(i) The variation of bunch length with current has been measured by utilizing a wide band pick up signal and a fast digitizer (which has been calibrated by measuring the bunch length for various RF-peak voltages). The results are shown in figure 8, for RF-voltages of 0.35, 0.5, 1.0 and 1.5 MV. In the turbulent regime, where the bunches are longer than the effective pipe radius, the variation of the bunch length is proportional to $I^{1/3}$. From the ratio of this dependence a longitudinal broad band impedance of $|Z/n|$=0.75 Ω was derived.

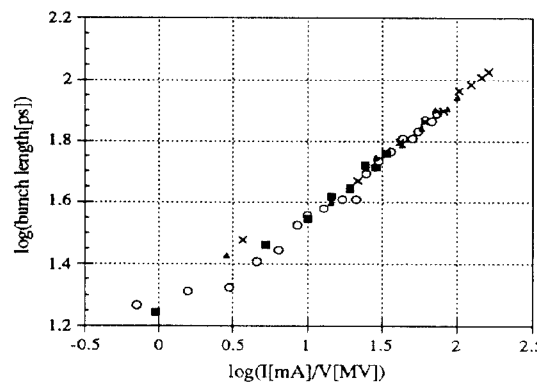

Figure 8. Bunch length as a function of current (with RF peak voltages of 0.35, 0.5, 1.0 and 1.5 MV)

(ii) The variation of tunes with current can be used to evaluate the imaginary part of the transverse impedance. A relevant change could only be observed in the vertical plane. At zero bunch current the slope becomes $\Delta Qy/\Delta I$= -0.000128[mA^{-1}], from which a transverse shunt impedance of 130 kΩ is calculated. The longitudinal impedance derived from this value by assuming a circular chamber geometry is $|Z/n|$ = 0.75 Ω, if a cut-off frequency of 2.2 GHz is used. Only a marginal variation of the horizontal and synchrotron tune with bunch current could be observed.

(iii) To define the bunch length dependence of the loss factor, the change in synchronous phase with bunch current has been measured for different RF-voltages. By fitting the variation of the loss factor with bunch length, the broadband resonator model (f_r, Q, R_T) can be been derived.

3.7 Ion trapping

Ion trapping was observed for uniform beams and fillings with small gaps [16]. It was found, that the measurements depend very sensitively on machine parameters, especially also on small non-uniformities in the filling structure which are always different between two injections. It was therefore very difficult to perform reproducible experiments. Figure 9 shows the variation of vertical tune and beam sizes during a trapping process. Curve a) shows the variation of the vertical tune. It is linearly increasing up to a current of about 55 mA, where the beam sizes start to blow up, as can be seen from curves b) and c). As a consequence the focusing forces are reduced and the linear tune increase is interrupted.

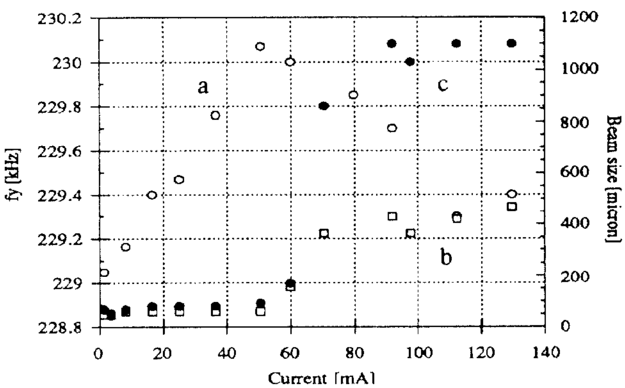

Figure 9. Vertical tune shift (a) and beam sizes (horizontal b, vertical c) as a function of current

Ion trapping in ELETTRA goes always parallel with a coherent beam-ion instability. At small currents, peaks of low frequency oscillations (0.5 - 40 Hz) can be observed on top of a broad spectrum which ranges up to about 50 Hz. Beyond a threshold current, the motion becomes unstable and a vertical pulsing becomes visible on the synchrotron radiation profile monitor. Figure 10 a) gives an example for the frequency change of the basic coherent mode as a function of current. Diagram b) shows the change in lifetime as a function of current.

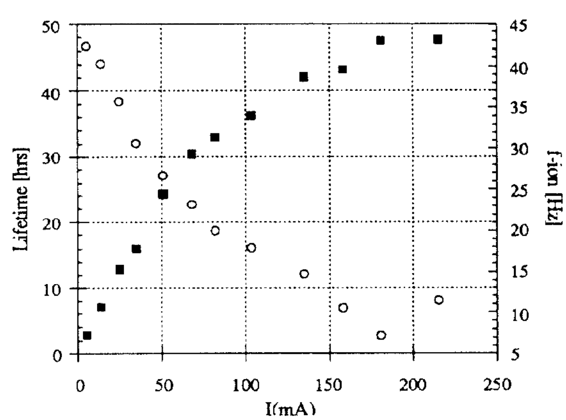

Figure 10. Coherent ion instability: oscillation frequency (squares) and lifetime (circles) versus current

If a sufficiently large gap is introduced in the filling, no ions are trapped, i.e. the tunes remain constant and no low frequency spectrum is observed.

4. OPERATIONS AND OUTLOOK

ELETTRA a is presently running in a sequence of 3 weeks operation, followed by a two weeks shut down. Starting from July 1st, 1994, about 55% of the operations time will be dedicated to scientific experiments, which at present are running at an energy of 2 GeV. The injection energy has been set to 1.1 GeV in order to guarantee reliable linac operation. By ramping the storage ring, any energy between 1.1 GeV and 2.3 GeV can be chosen for operation.

Future work will comprise the development of an elliptical insertion device, micro-undulators and the implementation of a new generation of insertion device vacuum chambers with even lower gaps. Furthermore the work on a cavity gun for the linac, the infrared FEL and a new cavity with waveguide mode suppresser will be continued.

5. REFERENCES

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