BEAM DENSITY MANIPULATIONS IN THE ELETTRA STORAGE RING

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Abstract

Low energy third generation light sources, such as ELETTRA, are lifetime limited by Touschek scattering. In principle an improvement of the lifetime can be obtained by increasing the emittance coupling or by increasing the longitudinal bunch dimensions, however, both methods have an adverse effect on the light quality. The trade off between lifetime and light quality in ELETTRA is discussed and spectral measurements for various scenarios are presented.

1 INTRODUCTION

One of the main difficulties facing third generation light sources is the low lifetime associated with the low emittance of these machines. The lifetime restriction arises from an enhancement of the Touschek effect, an effect which involves large angle intra-beam Coulomb collisions, and is evidenced in low emittance machines because of the higher density of the bunches. Increasing the lifetime without compromising the quality of the light is one of the desired goals in machine operation. There are several techniques for the improvement and involve either an increase in the storage ring particle acceptance or a reduction in the particle density. The former can be performed by increasing the dynamic aperture for off-momentum particles which must be done both longitudinally and transversely. The longitudinal acceptance increase may be performed by increasing the radio-frequency voltage applied to the beam. The method is costly and may involve upgrading the rf plant and/or the power feed-through to the cavity, or the installation of additional cavities and plant units. New methods have recently been proposed to increase the rf voltage by including in the ring a super conducting cavity operating at zero phase providing voltage only for those particles which have suffered an energy loss, either through a Touschek event or gas Bremsstrahlung. Increasing the transverse off-momentum acceptance is more complicated for an existing machine since the placement of additional sextupoles will require space which is generally hard to find. For machines in the development stage new lattices are being designed providing more than four percent energy acceptance [1].

The second technique for an improvement of the Touschek lifetime is to reduce the bunch density. Apart from increasing the number of bunches for a given current, the density reduction may be performed in either the transverse or longitudinal plane. However, this is in conflict with the goal of modern light sources and compromises the quality of the light, since increasing the transverse bunch dimension will reduce the brightness and lengthening the bunch will spoil the time structure and may enhance energy spread contributions. Transversely, the natural coupling of the machine may be increased either with skew quadrupoles or by operating on the coupling resonance. Longitudinally the bunch may be lengthened by a higher harmonic cavity [2] with precautions being taken not to increase the energy spread of the beam.

2 CONDITIONS IN ELETTRA

ELETTRA, which is Touschek limited in the longitudinal plane, at present operates with an effective accelerating voltage of 1.76 MV. This provides an overall lifetime (including gas scattering) of ~10 hrs at 250 mA under the conditions of reduced longitudinal multibunch instabilities (LMBI), see below. Going to the maximum voltage of 1.96 MV gives little improvement and increases the overall lifetime to 11.4 hrs. As to increasing the number of bunches in the ring a small improvement may be performed by going to 100% filling rather than the 80-90% currently used. This, however, would increase the likely-hood of ion trapping effects and generally gives a noisier beam. The method chosen to increase the lifetime is to operate with a controlled amount of longitudinal multi-bunch instability. The instability leads to a bunch dilution in the longitudinal plane as described in ref [3]. The control is performed by temperature tuning of the cavities with additional control being given by the adoption of Higher Order Modes frequency shifters [4] for operation at higher currents. The excitation can be varied from no modes being excited to full excitation. An intermediate regime corresponding to reduced longitudinal multibunch instabilities (LMBI) is characterised by coherent coupled bunch oscillations of a few degrees. The effective beam energy spread in this case is determined by the oscillation amplitude. The lifetime, however, is fully Touschek dominated since the bunch suffers little dilution. To obtain a bunch dilution the bunch has to perform larger oscillations which then Landau damp. The resulting average energy spread has to be evaluated taking into account the damping time in the longitudinal plane. Estimates indicate that the increase in the rms energy spread is two to three times the natural value of 8×10^{-4}. In addition to increasing the lifetime this mode of operation also helps in combating the strong transverse modes.

3 MEASUREMENTS

Experiments were performed on two beamlines and spectra were recorded under various operating conditions to estimate the effect of choosing to increase the lifetime via longitudinal bunch dilution. There are essentially three distinct ways to manipulate the lifetime at

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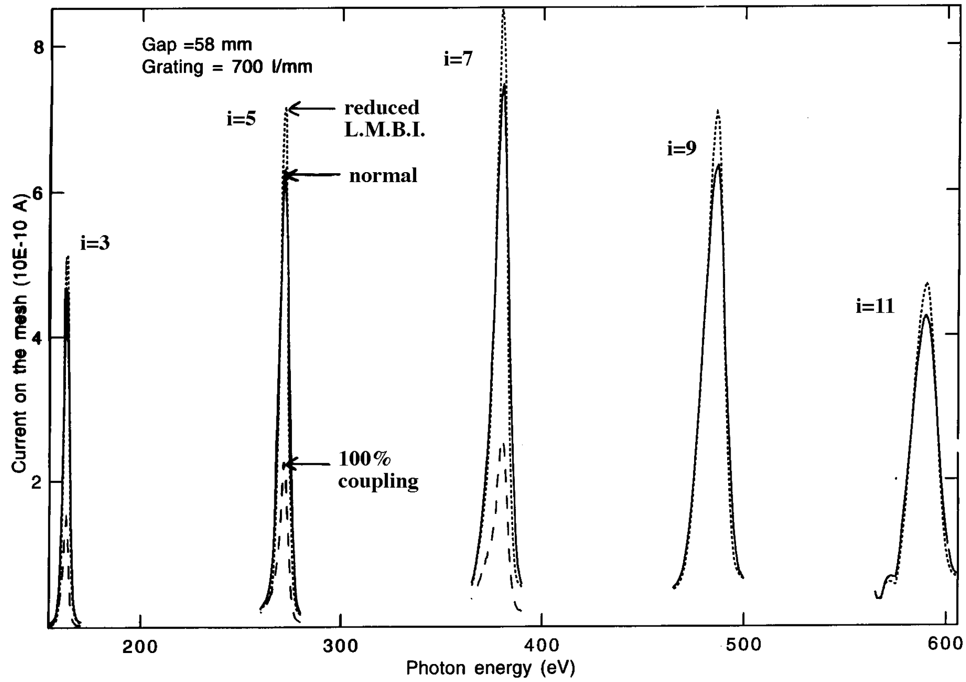

Figure 1: Line spectra taken on the ID_3, VUV beamline as a function of the different methods to increase the beam lifetime. Spectra shown refer to reduced longitudinal multibunch excitation, normal operating conditions (x2 increase in energy spread) and 100 % coupling.

ELETTRA. These are (a) controlled use of longitudinal multibunch excitation, (b) compensation or not of the spurious vertical dispersion and (c) excitation of the coupling resonance to increase the vertical beam size. The spurious dispersion, horizontal and vertical, affects the emittance by altering the equilibrium between quantum excitation and radiation damping. Additionally the dispersion alters the beam size via the energy spread of the beam. This effect is relevant to both planes and is particularly important when coupled bunch instabilities are driven by the cavity higher order modes. The spurious dispersion is most damaging in the vertical plane, and given the low geometric coupling accounts for most of the vertical beam dimension if not corrected. The natural coupling has been measured to be 0.1% (Δf_{min} of 6kHz) and the uncorrected vertical dispersion can have a peak rms values of up to 3.5 cm. The amount of effective emittance coupling as a function of vertical dispersion can be found in ref [5] and shows that an rms dispersion of 1.5 to 0.3 cm will change the dispersion caused coupling from 1.0 to 0.05%. The correction has been described elsewhere [5] and final rms values of 3 mm have been attained. Table 1 shows the lifetime for these three conditions. In the table a reduced LMBI condition corresponds to the description given in the preceding paragraph, whereas normal vertical dispersion has been taken to be 1.0 cm and the reduced dispersion as 3 mm rms. We note that the lifetime can be varied by a factor of five.

The lifetime is composed of gas scattering effects (elastic and inelastic) and the Touschek effect. To compute the Touschek contribution under stable beam conditions the bunch length has been taken to have the nominal value of ~18 ps at 250 mA for 80% filling (harmonic number of 432). The bunch length at this current is below the microwave instability threshold (the measured longitudinal broadband impedance |Z/n| is below 0.7 Ω). From fitting the lifetime contributions to the measured data results in an estimate for the bunch length or energy spread increase of a factor of two when operating under normal conditions.

	LMBI	Vertical Dispersion	Coupling	τ[hrs]
1	reduced	reduced	normal	6.7
2	reduced	normal	normal	10.3
3	normal	normal	normal	20.0
4	reduced	normal	maximum	30.0
5	normal	normal	maximum	36.5

Table 1: Lifetime as a function of controlled longitudinal multibunch instability (LMBI), spurious vertical dispersion and coupling. (250 mA, 2.0 GeV)

Figure 1 shows the effect on the undulator line shapes for the three cases examined on the VUV beamline (ID_3: period of 12.5 cm, N=36). The findings can be summarised as follows: exactly on the coupling resonance (reduced LMBI) for ID_2 a 10-15% reduction in intensity is observed whereas for ID_3 a reduction of 70% is noted and the noise level is greatly increased (the latter beamline uses an 20 μm entrance slit while the former does not). Going from a situation with reduced LMBI to normal LMBI operating conditions gives a reduction in intensity of 16-28% for ID_2 and a reduction of 10-13% for ID_3.

4 PHOTON COHERENCE

An important parameter is the fraction of coherent radiation emitted from an undulator. Diffraction limited effects are most noticeable at long wavelengths. Figure 2 shows the coherent fraction of emitted radiation for different horizontal to vertical emittance couplings in ELETTRA as a function of photon energy. The greatest effect, as expected, is found in the vertical plane. A summary is given in table 2. From these results we see that increasing the vertical emittance is not an attractive option. Table 3 shows the reduction in intensity as a function of energy spread for the two beamlines in consideration. We note a small overall effect on the results for the first few harmonics under consideration.

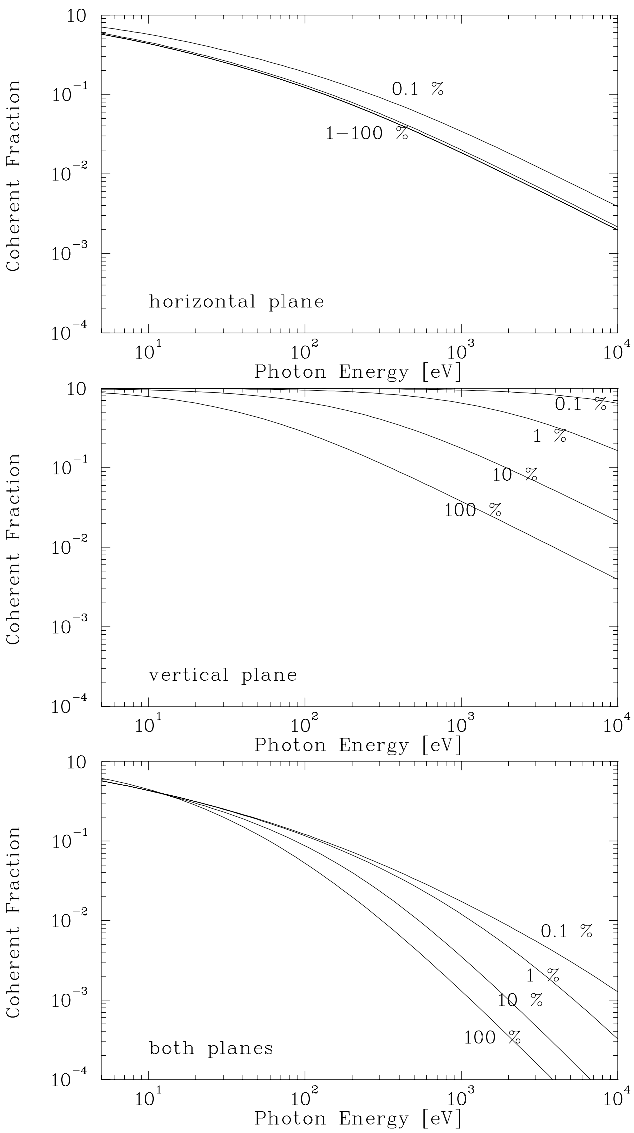

Figure 2: Coherent fraction of undulator radiation for (a) the horizontal plane, (b) the vertical plane and (c) the combined effect.

Photon Energy [eV]	Diffraction Limited to a Coupling of
10	100%
100	10%
1000	1%

Table 2: Extent of diffraction limit (within 20-30%) as a function of coupling.

Harmonic	ID_2 (N=81)	ID_3 (N=36)
1	-4%	-1%
3	-23%	-7%
5	-35%	-16%

Table 3: Theoretical reduction in intensity due to doubling the beam energy spread (worst case, zero emittance on axis).

5 CONCLUSIONS

These preliminary results indicate that increasing the bunch length and the associated energy spread by means of controlled residual coupled bunch excitation gives acceptable reduction of undulator flux whilst doubling the lifetime. Increasing the lifetime by increasing the vertical dimension by operating on the coupling resonance gives too great a reduction in flux and intensity and additionally results in the production of noisy spectra. In view of future developments to increase the stored current and to combat the consequently enhanced coupled bunch instabilities options to provide adequate Touschek lifetime using other methods are being actively pursued [6]. These involve the use of bunch lengthening techniques using a higher harmonic cavity (super conducting) or the installation of a super-conducting cavity for additional rf acceptance (without bunch lengthening) as described above. The choice will be based on the feasibility of increasing the transverse off-momentum acceptance.

6 ACKNOWLEDGEMENTS

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