Optics and Transverse Beam Dynamics in ELETTRA

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Abstract:

During the commissioning of the ELETTRA Strorage Ring, an intensive program of measurements regarding linear optics and non-linear dynamics has been carried out. With the aid of high level programs and the available diagnostic instrumentation, measurements of the tunes, the optical asymmetries, the dispersion and of the coupling together with resonance scans in the tune diagram have given valuable help in the understanding of the machine. In this paper, the results of the above measurements are presented.

1. INTRODUCTION

ELETTRA is the 1.5-2.0 GeV third generation synchrotron light source constructed in Trieste, Italy. The facility is composed of a full energy Linac, currently operating at 1.1 GeV, a Transfer Line and a Storage Ring. The latter has been concepually designed to have a low emittance of 4.0 nm and 7.1 nm, at 1.5 and 2.0 GeV respectively. The lattice is of the expanded Chasman-Green type composed of twelve double bend achromats with expected horizontal and vertical tunes of 14.3 and 8.2. The beta functions, shown for one achromat in Figure 1 together with the dispersion, are expected to be 8.2 m horizontally and 2.6 m vertically in the center of the dispersive free straights, and the maximum dispersion is 0.4 m. Two families of sextupoles have been placed in the dispersive arcs in order to compensate for the large horizontal and vertical natural chromaticities of -43.0 and of -14.0. An additional harmonic sextupole family, located in the non-dispersive straights, has been optimize to minimize non-linear effects and to enlargen the dynamic aperture. Insertion devices may be accomodated in eleven of the straight sections, where additional quadrupole families might be used for linear distorsion compensations.

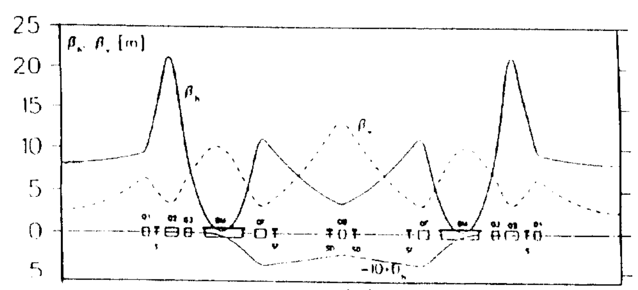

Figure 1. Theoretical Beta Functions in one Achromat

Commissioning of the Storage Ring started in October '94 and within a couple of days, it was possible to accumulate a stored beam. Ever since, all the major performance goals [1] were achieved, reaching 530 mA in multibunch, a beam current greater than 50 mA in single bunch and an energy of 2.3 GeV by energy ramping the Storage Ring [2]. The ring is now routinely operating at 2.0 GeV with a lifetime of 10 h at 100 mA and delivering synchrotron light from three insertion devices to their respective beam lines.

During these eight months, intensive measurement programs have been carried out in order to understand and determine all the linear and non-linear performances of the lattice. Many results were obtained with the aid of in house developed high level software applications [3], which automated many measurements. In this paper, the results of the measurements are presented.

2. LINEAR PERFORMANCE

Even though an eventual commissioning relaxed optics, less sensitive to magnet errors, had been designed [4], all the commissioning has been achieved with the low emittance optics right from the start. Both the first turn and the first accumulation of the beam were obtained with all the correctors switched off and by Fourier analyzing the first turn orbit, the integer parts of the tunes were verified to be correct. The first accumulated beam presented a 'natural' closed orbit with a horizontal and a vertical rms value of 6.3 and 4.1 mm respectively. The fractional parts of the tunes were determined with the tune measurement system and found to be above integer, even though with fairly different values from the expected ones. Subsequential orbit corrections and studies, during which a systematic error in the beam position monitoring system was detected [5], brought the closed orbit down to 0.15 mm rms, 0.0 average and less than 1 mm peak to peak values in both planes. Consequently the fractional parts of the tunes converged within 15% to the expected values, showing clearly the feed-down effects of the sextupoles By a slight modification of the settings of the quadrupoles in the dispersive free sections, the tunes are currently set to their nominal values of 14.3 horizontally and 8.2 vertically.

Extensive measurements were performed to determine the optical asymmetries. The techniques used were post-processing of the measured sensitivity matrices and correlating tune shifts to quadrupole setting variations. Both methods reveal that the current lattice presents a beta beat in the range of 10 to 15%, the source of which has yet to be found.

Correlations of the measured dispersion with the closed orbit parameters were also noticed and found to be consistent with optical computations [6]. A closed orbit horizontal rms of 0.5 mm typically gave distorsions of the order of 25% and a beating behaviour with consequential leakages of ±0.1 m in the theoretically dispersive free sections. The dispersion with the current orbit presents a 10% agreement with the theoretical one. However, even for a well corrected orbit, the lattice still presents a residual vertical dispersion of about 4 cm, for which correction will be performed in the near future. The estimated coupling $\varepsilon_y/\varepsilon_x$ due to the spurious vertical dispersion has been evaluated to be in the range of 3 to 5%.

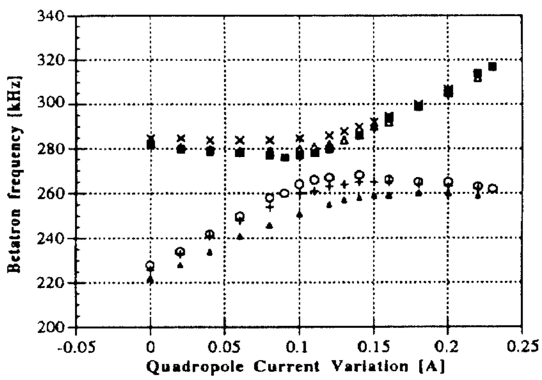

Figure 2. Measurement of the difference coupling resonance

As for the coupling due to skew quadrupole effects, the width of the difference coupling resonance has been measured by varying a focussing quadrupole and recording the resulting betatron frequencies. Results showed a coupling of $\varepsilon_y/\varepsilon_x$ = 0.6% and were confirmed by repeating the measurements after displacing locally the vertical orbit to 1.0 mm and 2.0 mm in a focussing sextupole. A graph of the measurement is shown in Figure 2, where the betatron frequencies are drawn as a function of the quadrupole settings' variation for the various displacements. It can be clearly seen that the displacement in the sextupole enlargens the minimum distance between the betatron frequencies.

As stated in the previous section, three insertion devices, whose period numbers, period lengths and effective maximum on axis fields are reported in Table 1, are currently operational with minimum gaps which go from 26 mm for W15.0 to 32 mm for U12.5. For each device, the relative effects on the beam were measured as soon as it became operational. All devices presented no significant change in the closed orbit when set to minimum gap The vertical tune shifts recorded at the pessimistic energy of 1.1 GeV were found to be 0.008, 0.011 and 0.015 for U5.6, U12.5 and W15.0 respectively, in complete agreement with the theory. The horizontal tune shifts were found to be less than 0.001. Beta assymetry measurements, performed with all three devices at minimum gaps, revealed a 12% maximum beta beat with respect to the current lattice, also in good agreement with the theoretical expectations. The overall vertical tune shift was recorded to be 0.036.

Regarding the emittance of the ring, measurements were performed using the Synchrotron Beam Profile Monitor. At 2.0 GeV the results agreed with the theoretical emittance within 20%. An approximate confirmation came from a new technique, still to be optimized, based on analyzing the spectral lines of light from an undulator [7]. However, the emittance was found to be larger than expected at 1.1 GeV probably due to intra-beam scattering effects.

Table 1
Insertion Device Parameters

ID	No. Periods	λ [m]	Bo [T]
U5.6	81	0.056	0.41
U12.5	36	0.125	0.50
W15.0	10	0.150	1.12

3. NON-LINEAR PERFOMANCE

One main concern in low emittance machines is the non-linear transverse beam dynamics. The fairly large sextupole settings in combination with multipoles in the magnets may render injection particularly difficult. In addition, the non-linearities coming from the low gap insertion devices may reduce the lifetime, deteriorating the machine performance. In this respect, non-linear measurements, which included resonance scans and dynamic apertures, have been carried out.

Regarding problematics associated with injection, the current settings of the machine give a capture efficiency of 95%, leading to the conclusions that the region in the tune diagram around the nominal tunes, experienced by the injected electrons, is free of strong resonances. Since the main role of the harmonic sextupole is to enlargen the dynamic aperture by containing the tune shifts with amplitudes, a further conclusion is that it is quite well optimized for the present settings of 0.5 for the chromaticities in both planes. Deeper studies on its influence have not been carried out yet.

Resonance scans were performed in order to determine the stopbands of the integer and half integer resonances and to get a mapping of the existing resonances in the first quadrant of the tune diagram. Measurements of the integer stopbands have shown a reduction in the widths when the rms of the closed orbit passed from 0.80 to 0.15 mm in both planes. The horizontal stopband width was reduced from 0.045 to 0.036 and the vertical one from 0.035 to 0.022. However, no reduction was noticed for the vertical half integer whose width was measured to be 0.009 in both cases. The horizontal half integer stopband was measured only for the well corrected closed orbit and was found to be 0.014. An enlargement of the vertical integer and half integer stopbands was noticed when closing all three insertion devices to minimum gaps. On this occasion the values were found to be 0.031 and 0.012 respectively. The large integer width increase may be explained by an overlapping with a fifth order difference resonance and might need further studies.

A mapping of higher order resonances was made. Mainly normal and skew third order resonances were found, all of which presented strong effects on the beam with significant beam losses. In order not to report too many numbers, for every resonance we report the quantity δ at which a significant drop in lifetime occurred. δ is defined as $\delta = p - nQ_x - mQ_y$ where p is an integer, $|n|+|m|$ is the order of the resonance and Qx, Qy are the horizontal and vertical tunes. A particularly strong effect was seen by $3Q_x = 43$ with $\delta = 0.028$. The other two third order resonances found were $2Qx + Qy = 37$ with $\delta = 0.015$ and $Qx + 2Qy = 31$ with $\delta = 0.023$. No particular dependence of the widths on the rms of the closed orbit was noticed. During the resonance scans no clear evidence of satellite resonances, due to the four RF cavities located in dispersive arcs, was seen to affect the machine performance.

Dynamic aperture measurements were performed with a horizontal and a vertical scraper located at the end of an insertion device straight. Lifetimes were recorded as a function of the width for each scraper with 150 mA at 1.1 GeV and a well corrected orbit. A maximum horizontal amplitude of 15 mm and a vertical one of 8 mm were found. The same measurements were performed with all three insertion devices at minimum gap. During the latter, compensation for the induced vertical tune shift was achieved. Figures 3 and 4 show the results for the horizontal and vertical dynamic apertures. There is a clear reduction of 3.0 mm in the horizontal plane and of 1.0 mm in the vertical one due to the insertion devices. Dynamic aperture simulations, Figure 5, were performed with same machine conditions, ignoring however multipoles and closed orbit deviations. The results show a consistent reduction in the vertical plane. Measurements were reperformed at 2.0 GeV for the vertical dynamic aperture. For this energy, the dynamic aperture did not seem to be affected by the insertion devices.

4. CONCLUSIONS

The commissioning of the Elettra Storage Ring was based on extensive measurements which confirmed a good agreement of the lattice with the original design. The introduction of three insertion devices, even at low energies, did not constitute a problem.

5. REFERENCES

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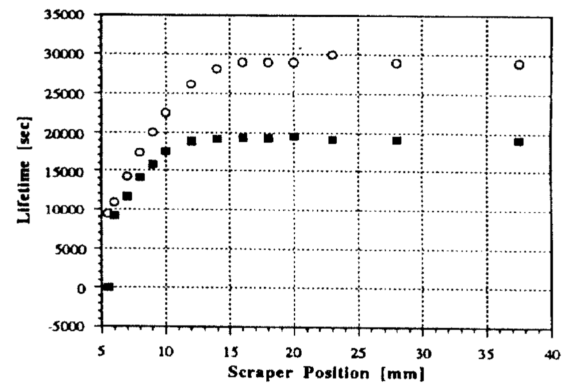

Figure 3. Horizontal dynamic aperture measurement with (black) and without (white) insertion devices closed at minimum gaps.

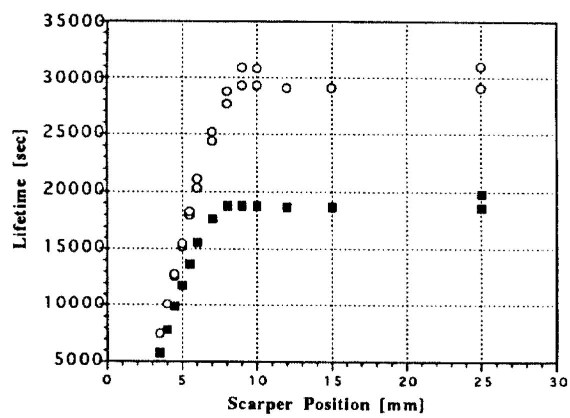

Figure 4. Vertical dynamic aperture measurement with (black) and without (white) insertion devices closed at minimum gaps.

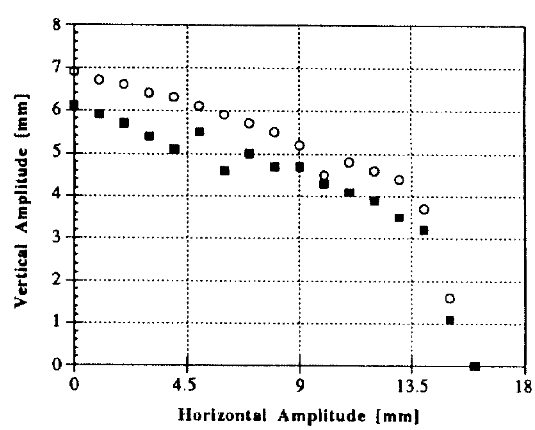

Figure 5. Dynamic aperture by simulation with (white) and without (black) insertion devices at minimum gaps