OPERATION OF THE SUPER-ACO FREE ELECTRON LASER WITH A FEEDBACK DAMPING QUADRUPOLAR COHERENT SYNCHROTRON OSCILLATION

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Abstract

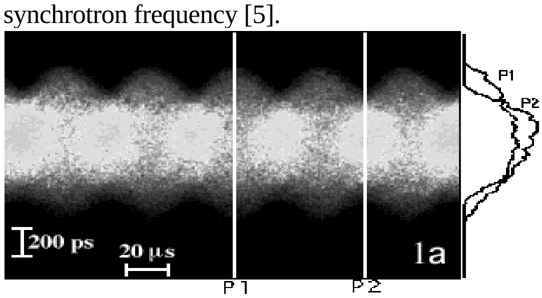
Up to now, the operation of the Super-ACO storage ring Free Electron Laser (FEL) at high current still represented a challenge due to the presence of the quadrupolar coherent synchrotron oscillations. So, a feedback damping them has been installed on the storage ring. As a consequence, beam parameters and FEL performances have been measured.

1 INTRODUCTION

The free electron laser is a coherent, tunable light source produced by the interaction of electron bunches passing through an undulator and synchrotron radiation stored in an optical cavity [1]. So far, constant improvements of the Super-ACO FEL in terms of lifetime, stability [2] and power allowed us to perform the first and unique applications of a storage ring based FEL in biology and in surface physics [3]. Nevertheless, increasing the laser extracted power and improving the compatibility with normal users of synchrotron radiation requires the FEL at higher current. Though, above a current threshold (around 30 mA per bunch), the establishment of quadrupolar coherent synchrotron oscillations spoiled the stability of the FEL and can even prevent its start-up [4]. We present in the paper how the use of a feedback damping this particular instability allowed to stabilize the beam and to improve FEL performance.

2 STABILISATION OF THE BEAM

The quadrupolar coherent synchrotron oscillations consist of quasi-sinusoidal oscillations of the bunch length (see figure 1) with a frequency close to twice the synchrotron frequency [5].



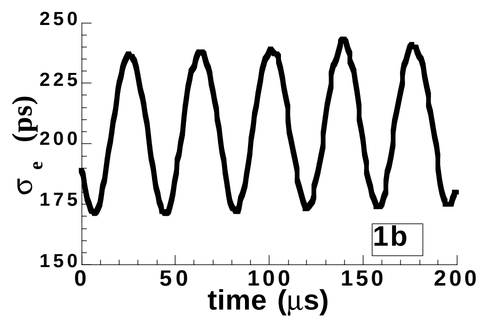


figure 1 : In a), Quadrupolar mode of coherent synchrotron oscillation at 26.5 kHz measured with a double sweep streak camera, horizontal range = 200 µs, vertical range = 1.7 ns, examples of electronic density profiles (P1 and P2) corresponding to vertical slices of the image are displayed on the right side of the figure. In b), the RMS bunch length σ_e versus time (analysis of the image 1a), I =87 mA for two bunches stored in the ring.

First proposed by J. Gareyte (CERN), a new feedback system (figure 2) was implemented on Super-ACO. Quadrupolar modes (QM's) are detected with a pick-up running electrode on the 293 rd harmonic of the bunch revolution frequency. Passing through some filters , the signal is used to modulate the RF cavity voltage after loop phase and gain adjustments to cancel the QM.

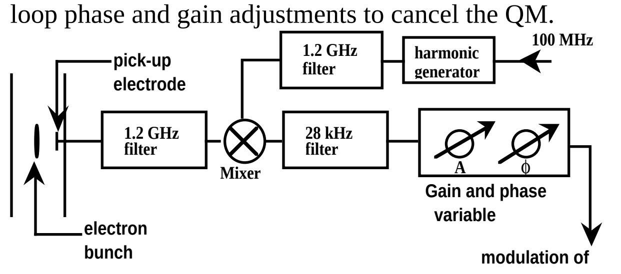


figure 2 : Scheme of the feedback damping the quadrupolar coherent synchrotron oscillations.

Measurements performed with a double sweep streak camera (see figure 3) show that the feedback system is quite effective. Indeed, over the whole current range where the QM's were ordinary present (fig. 1), the beam longitudinal distribution now appears stable (fig. 3) due to the quadrupolar feedback (QF).

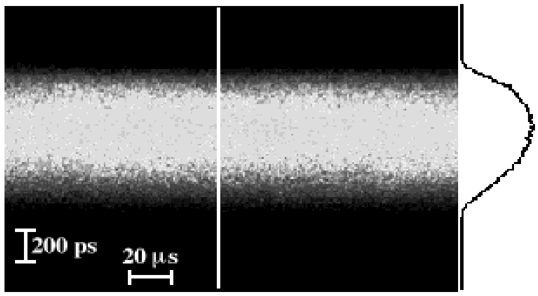


figure 3 : Double sweep streak camera image, horizontal range = 200 µs, vertical range = 1.7 ns, I = 80 mA with the quadrupolar feedback damping the quadrupolar coherent synchrotron oscillation, the bunch shape does not oscillate anymore as in figure 1.

In addition, the threshold, for sextupolar coherent synchrotron oscillations is lowered to 84-85 mA while it was above 90 mA without the QF. The competition previously existing in this current area between the quadrupolar and the sextupolar modes disappeared, allowing the latter to become established more easily.

The longitudinal behaviour being modified by the QF, we measured the bunch length versus the current with the double sweep streak camera (figure 4).

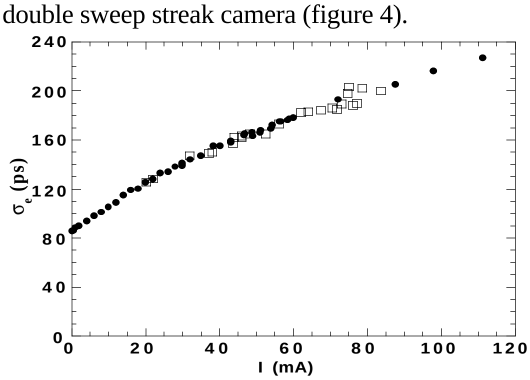
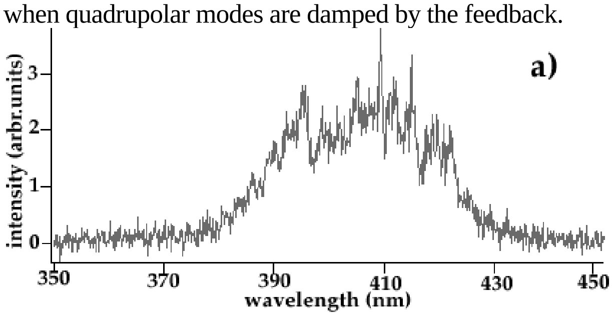


figure 4 : σ_e, RMS bunch length versus the total current in the ring, (●) quadrupolar feedback off, (❐) quadrupolar feedback on.

The averaged bunch length remains identical in presence of the quadrupolar feedback. The energy spread, an important issue in the operation of the FEL has been also measured using a method based on the measurement of the synchrotron radiation spectrum emitted by our optical klystron type insertion device [6]. Figure 5a shows that in presence of the quadrupolar modes the spectrum is strongly degraded, interference fringes are blurred, which is very harmful for FEL operation. On the other hand, the spectrum is quite correct for the FEL operation (fig. 5b) when quadrupolar modes are damped by the feedback.



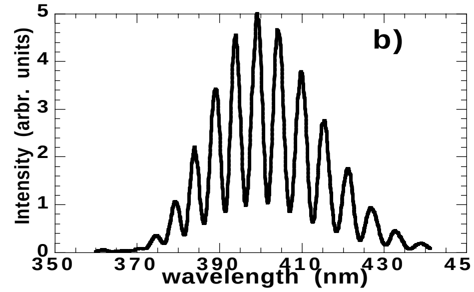


figure 5 : FEL optical klystron spectra at high current. In a), the spectrum is degraded by quadrupolar oscillations, in b) with the quadrupolar feedback, the spectrum is normal.

Moreover, the energy spread curve versus the total current in the ring previously measured up to 60 mA (below the threshold of quadrupolar oscillations) has been extended up to 115 mA due to the quadrupolar feedback (figure 6).

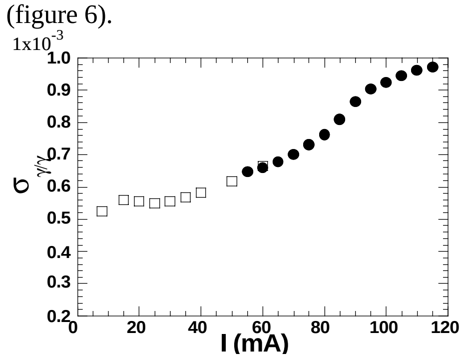


figure 6 : energy spread $\sigma_{\gamma/\gamma}$ versus the total current I, quadrupolar feedback off (❐) and quadrupolar feedback on (●) measured using the optical klystron fringe method.

The beam is governed between 0 and 32 mA by potential well distortion since the energy spread stays at the theoretical value while the bunch length increases. Above 32 mA, due to the microwave instability, the energy spread grows very fast versus the current, particularly between 80 and 95 mA. In this current range, sextupolar oscillations are established, so it could explain this strong increase of energy spread.

3 FEL EFFECT ON THE BEAM

In previous papers, it has been showed that the FEL could stabilise the beam by damping quadrupolar coherent synchrotron oscillations. In the same way, with the quadrupolar feedback damping the latter, the laser damps the sextupolar coherent synchrotron oscillations (figure 7).

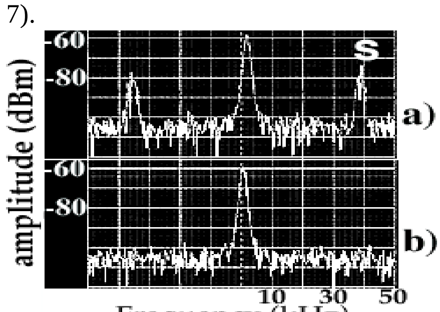


figure 7 : measurements of the sidebands with a spectrum analyser. In a), FEL is off, presence of sextupolar coherent synchrotron oscillations (S) at 36.8 kHz. In b), FEL on, the sextupolar modes are damped.

Basically, the laser electric field induces a microbunching of the electrons inside the bunch at the laser optical wavelength (350 nm), incoherent from pass to pass. By this fact, a coherent motion of the whole bunch, either quadrupolar or sextupolar, is prevented. The FEL destroys the coherence between the electrons because it adds on the beam an incoherent perturbation.

4 FEL PERFORMANCES

The damping of the quadrupolar modes by the feedback is very useful for FEL operation at high current. First, it allows a very easy start-up of the laser and extends its operation over a wider current range. Moreover, the laser extracted power was increased by a factor of two with respect to previous operation at 60 mA, below the quadrupolar oscillations threshold. Indeed, theory predicts that the laser power depends on the synchrotron power, itself proportional to the total current stored in the ring. Measurements of the total extracted laser power (figure 8) fit with a linear dependence with the current.

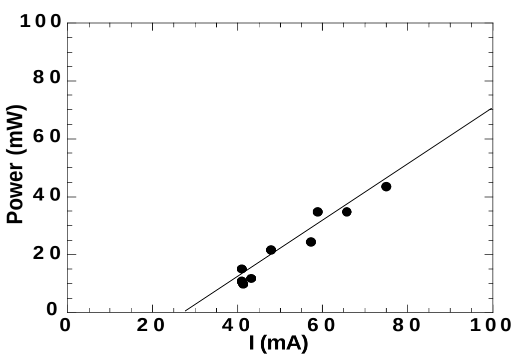


figure 8 : total laser power (black points), transmitted through both sides of the optical cavity, versus the total current stored in the ring and a linear fit (plain line).

Thus, the FEL operated at 100 mA in presence of the QF offers to users an enhanced laser power.

Besides, the stability of the FEL was greatly improved as illustrated in figure 9.

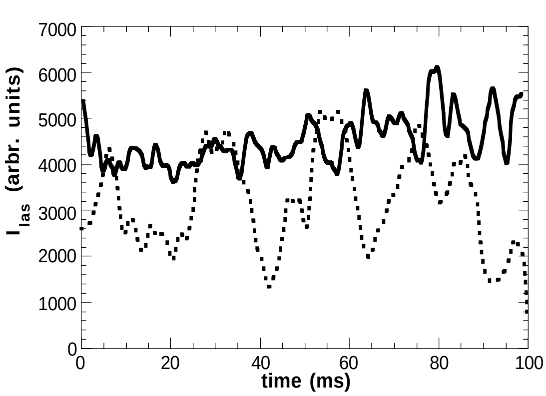


figure 9 : laser intensity (I_{las}) versus time. Without feedback (dashed line), the laser macrostructure is unstable and pulsed. Feedback on (plain line), the laser is "cw" (reproducing the electron two bunches revolution frequency ≈ 8.3 MHz).

Due to the competition with the quadrupolar modes, the laser intensity adopts an almost erratic macropulsed regime. When the QF is used, the laser intensity is quasi-cw, more stable although it is fighting against the sextupolar oscillations. Therefore, the presence of these latter seems to be less harmful for the FEL operation but it probably degrades slightly the FEL stability. Moreover, a nearly complete stabilisation is obtained using a longitudinal feedback on the laser micropulse position [7].

CONCLUSION

Due to the feedback damping the quadrupolar coherent synchrotron oscillations, the Super-ACO FEL can be operated at high current up to 120 mA with greater power. The stability was also improved, allowing to perform user experiments. As a consequence of high current operation, the compatibility with synchrotron radiation users is improved.

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