POSSIBLE MICROSTRUCTURE IN THE SUPER-ACO FEL PULSE

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Abstract

Dynamical studies were carried out on the Free Electron Laser source implemented on the storage ring Super-ACO in Orsay (France). Among these, the structure of the Super-ACO micropulse has been observed with a double sweep streak camera, allowing to follow the profile of the distribution in time. Various situations can be observed, from a stable unique pulse, to several micropulses drifting in the time and changing in intensity. This substructure depends also on the tuning condition. The origin of this substructure can be explained according to various phenomena.

1 INTRODUCTION

The Super-ACO Free Electron laser (FEL) operates since 1989 in the visible and since 1991 in the UV [1]. The Super-ACO storage ring is operated at 800 MeV, the nominal energy of the ring. On Super-ACO was recently installed an active 500 MHz harmonic cavity, which is generally used in combination with the main 100 MHz cavity for the FEL operation [2]. The 3 m long optical klystron provides a maximum peak magnetic field of 0.45 T on axis. The 18 meters' long optical cavity allows to operate the FEL with a two bunch mode filling in the ring. First user applications started in 1993 for dynamical studies of a coenzyme [3], and were followed by two-color experiments coupling the UV FEL and the naturally synchronized synchrotron radiation for pump probe two color experiments in surface physics [4], in material sciences [5] and in chemistry and biology [6]. The stability and the structure of the FEL pulse is a very critical issue from an user point of view. Systematic studies were then carried out on the FEL temporal pulse measured with a Hamamatsu dual sweep streak camera [7].

2 THE SUPER-ACO TEMPORAL STRUCTURE VERSUS THE TUNING CONDITIONS

2.1 Detuning curve

The Super-ACO FEL exhibits a specific behaviour versus the synchronization between the electrons circulating in the storage ring, and the optical pulses bouncing back and forth in the optical resonator (detuning condition). The FEL pulses present a microtemporal structure, reproducing the recurrence of the electron bunches at a very high repetition rate. At the ms scale, it presents a so-called "macro-temporal structure". At perfect tuning, the FEL exhibits a "cw" regime (zone 3 in figure 1), expect the MHz high repetition rate reproducing that of the electron bunches. When the FEL is slightly desynchronized, the FEL power is very noisy and it shows a pulsed structure at the ms scale (zones 2 and 4). When the FEL is more desynchronized, it becomes again CW. The width and the shape of the detuning curve, as illustrated in fig. 1, depends on the gain to losses ratio, and on the shape of the electronic distribution. It is, for example, less symmetrical on Super-ACO with the 500 MHz cavity, providing a sharp rising edge on the electronic distribution because of a higher sensitivity to the microwave instability. A longitudinal model describing the FEL evolution allows to simulate such detuning curves [8]. A longitudinal feedback system has been developed in order to maintain the FEL pulse in zone 3, and to prevent it from jitter [9]. It also stabilizes the intensity fluctuations and the spectral drift of the FEL.

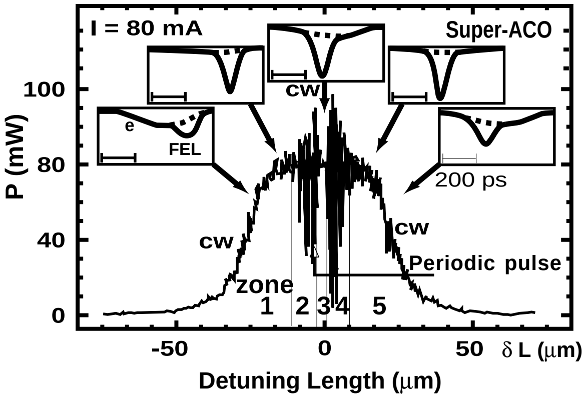

Figure 1: Detuning curve measured on the Super-ACO FEL. The synchronisation is changed by a modification of the RF frequency, and it is scaled here in cavity length variation. The insets show the longitudinal bunch distribution (- - -) and the FEL micropulse (___) measured with a stroboscopic detector, the dissector [10].

2.1 FEL micropulse versus detuning

Examples of the temporal structures measured with the double sweep streak camera are shown in fig. 2. Clearly, the FEL pulse structure seems rather homogeneous in zone 3, whereas one can see some rapid drifts in zones 1 and zones 5, in opposite signs. These opposite drifts can also be seen in the case of the pulse FEL. The detailed analysis of the images shows a drift speed of 85 ps/ms, or 10.2 fs per pass, which corresponds to the drift of the FEL imposed by the detuning (12 fs per pass for 10 Hz detuning). In that case, this rapid drift of the internal structure of the FEL pulse is directly related to the tuning condition of the FEL itself [11].

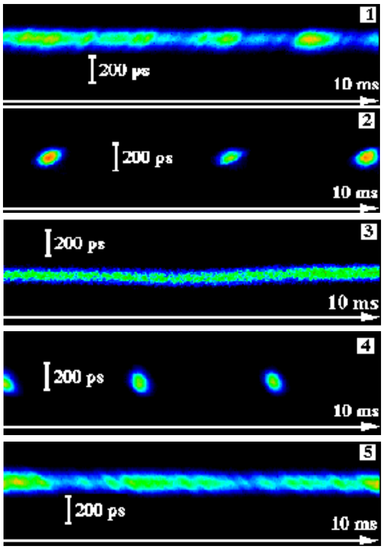

Figure 2: Streak camera images of the Super-ACO FEL for the different zones a) zone 1 : Δf_{RF} = - 50 Hz, δL = - 9 µm b) zone 2 : Δf_{RF} = - 10 Hz, δL = - 1.8 µm, c) zone 3 : Δf_{RF} = 0 Hz, δL = 0 µm, d) zone 4 : Δf_{RF} = 10 Hz, δL = 1.8 µm, e) zone 5 : Δf_{RF} = 50 Hz, δL = 9 µm.
A vertical cut provides the laser pulse distribution, which evolves in time as given by the horizontal axis.

3 MICROTERMPORAL STRUCTURE OF THE FEL PULSE AT PERFECT TUNING

3.1 Shape of the FEL pulse

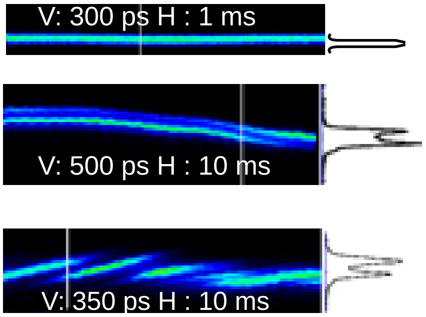

Figure 3: Streak camera images of the Super-ACO FEL at perfect tuning showing either a single stable gaussian distribution or several micropulses evolving simultaneously, or drifting in time. Profiles are shown on the right of the streak camera images.

Fig. 3 shows different profiles of the FEL micropulse observed on the Super-ACO. The stable gaussian FEL provides a situation where the FEL can be at the Fourier limit. When the FEL subpulses drift with respect to the synchronous electron, it then sees a lower electronic density, its intensity decreases and a new pulse can easily start with a higher gain at a different temporal position. The presence of substructure, also observed on the UVSOR FEL [12] has been investigated in more details.
Systematic analysis of the FEL micropulse distribution was carried out. The pulse duration, correlated to the laser linewidth measurement shows that the FEL can operate very close to the Fourier Limit. In that case, the FEL line is gaussian, but sometimes, some internal substructure can be observed.
One can also observe the splitting of the FEL micropulse into two subpulses, as shown in fig. 4. Such a situation appeared nevertheless 3% of the time of the FEL operation over one shift. The rest of the measurements showed a very stable gaussian distribution close to the Fourier limit.

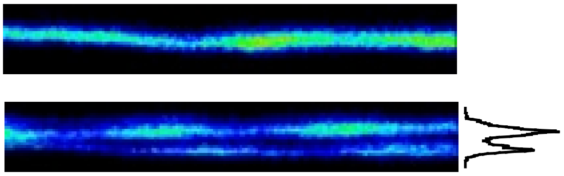

Figure 4: Streak camera image of the Super-ACO FEL mainly exhibiting a stable gaussian distribution (upper image) or which can split into two subpulses (buttom image). The total vertical scale is 200 ps, and the horizontal scale is 5 ms.

3.2 Substructure due to drifts and modulation

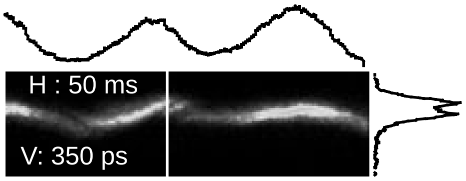

Figure 5: Streak camera image of the Super-ACO FEL at the perfect tunning showing micropulses. A horinzontal cut shows the intensity modulation at 50 Hz, and the vertical cut indicated on the image shows the presence of micropulses in the FEL distribution.

The simplest origin of the substructure in the FEL longitudinal distribution can come from perturbations on the electron beam or on the FEL itself. Especially, it has been observed that some line perturbations can affect the Super-ACO FEL. It first results in an intensity modulation, which can even lead to a chaotic regime when the perturbation is strong [13]. In addition, the longitudinal distribution is also modified : the RMS value is modulated, the center of mass of the distribution is displaced periodically, and some microstructure can appear. An example is illustrated in figure 5, where a substructure appears (see the longitudinal profile) and then, several ms afterwards, the FEL temporal distribution becomes gaussian again. Some modulation can also appear at higher frequencies on the Super-ACO FEL, and they are often multiples of the line frequency. Great care is carried out now in order to reduce the influence of the line on the beam itself. It has also been measured that the line perturbation from mechanical vibration can affect the FEL operation.
One can also observed a sudden jump in position of the FEL micropulse, as illustrated in fig. 6. It results into an artificial substructure of the FEL pulse, but it in fact correponds to the FEL response to a sudden jump of the synchronization condition.

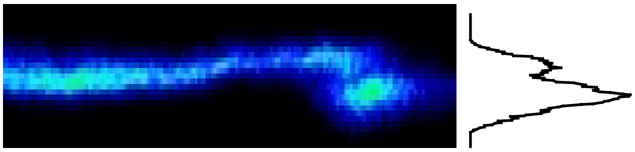

Figure 6: Streak camera image of the Super-ACO FEL at the perfect tunning a sudden jump in the FEL micropulse position, inducing a joint existance of two different FEL pulses. The vertical profile of this sudden transition is shown on the left, as if the FEL pulse would present some internal structure. The vertical axis is 200 ps, and the horizontal axis is 5 ms. A horinzontal cut shows the intensity modulation at 50 Hz, and the vertical cut indicated on the image shows the presence of micropulses in the FEL distribution.

3.3 Possible intrinsic effect

Except from sudden perturbation or modulations affecting both the electron beam and the FEL, one can wonder on the possibility of an intrinsic effect on the storage ring FEL beam dynamics. The drift speed of the FEL subpulse is strongly enhanced when the longitudinal feedback is operated on the FEL [9]. As the FEL always search for the maximum electronic density, a new FEL subpulse can grow when the previous one is drifting and vanishing. When two subpulses are evolving jointly as in figure 4, the physical origin of the internal microstructure can be related to a local modification of the electronic density.

4 CONCLUSION

The study of the profile of the longitudinal distribution has been performed. Various situations can be orbserved, from a single FEL gaussian pulse at the Fourier Limit to situations exhibing a complex internal structure. Eventhough a longitudinal feedback on the FEL is effectively stabilizing the FEL micropulse, there is not yet a full control of the shape and width of the micropulse. The FEL being a non linear system, with an action on the electron beam which is kept for many turns, the control of its performances depends in fact on many parameters, and the whole system is very sensitive to perturbations. The present operation for the Super-ACO FEL is nevertheless quite satisfactory from an user point of view.

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