Temporal and Spectral Stability of the Super-ACO Storage Ring Free Electron Laser Source

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Abstract

The Super-ACO UV FEL is used for applications such as a time-resolved fluorescence in biology [1] and two colors experiments (FEL + Synchrotron Radiation). For the purpose of characterizing and stabilizing the FEL for these users' experiments, we studied temporal and spectral behaviors of the laser micropulse under the various conditions of synchronization between a positron bunch and an optical pulse. A deformation of a temporal distribution of the laser micropulse, a drift of the lasing wavelength and a spectral evolution are observed. The preliminary results of simultaneous temporal and spectral measurements are obtained. Finally, a longitudinal feedback system is developed to keep the perfect synchronization between the positron bunch and the optical pulse.

1. INTRODUCTION

Most of the FEL applications usually demand good temporal and spectral stability of the light source.

At the Super-ACO FEL (λ=350nm), we can distinguish 5 operational zones depending on the synchronism condition between the positron bunch circulating in the storage ring and the optical pulse (fig.1) [2].

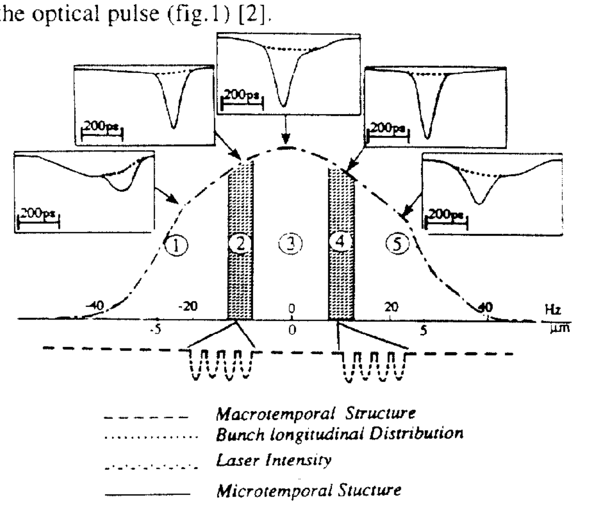

Figure 1. Five operational zones of the Super-ACO FEL depending on the detuning between the laser micropulse and the positron bunch. The macrostructure is cw in the zones 1,3 and 5, and pulsed in the zones 2 and 4.

In the zones 1,3 and 5 in fig.1, the laser shows a cw macrostructure at the msec time scale. The laser micropulse, which comes from the pulsed structure of the positron bunches in the storage ring, has the maximum intensity and presents a longitudinal jitter specially in the central zone 3 [3]. In the zones 2 and 4, the macrostructure of the laser is pulsed typically with the period of 3 msec.

The experimental set-up is shown in fig.2. We have two apparatus for temporal measurements, a dissector (stroboscopic pico-second detector) [4] and a streak camera (Thomson TSN 506) [5,6]. A monochromator (Jobin-Yvon) and a newly introduced scanning Fabry-Perot interferometer (Burleigh) are employed for investigating the spectral features of the laser.

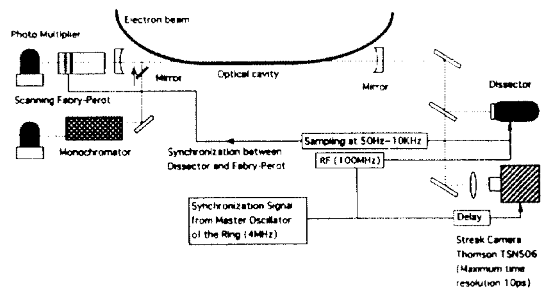

Figure 2. Experimental set-up.

2. TEMPORAL FEATURES

2.1. Dissector

The dissector has a temporal resolution of about 10psec and the sampling frequency of 300Hz. Since the dissector is a stroboscopic device and sampling over a large number of laser micropulses, the observed temporal width is affected by the micropulse jitter as the following manner,

$\sigma^2_{dissector}=\sigma^2_{RMS\ width}+\Delta\tau^2_{jitter}$,

where $\sigma_{dissector}$ is the measured RMS width with the dissector, $\sigma_{RMS\ width}$ is the measured RMS width with the streak camera or by the time-resolved fluorescence experiment (after deconvolution [1]) and $\Delta\tau_{jitterr}$ is the longitudinal jitter of the laser micropulse. In table 1, the two RMS widths and the estimated temporal jitters of the laser micropulse, which are obtained independently, are compared [1,3].

Table 1
Measured temporal width and jitter of the laser micropulse

	Experiment of streak camera	Time-resolved fluorescence
$\sigma_{RMS\ width}$	26ps	30ps
$\sigma_{dissector}$	40ps	45ps
$\Delta\tau_{jitter}$	30ps	33ps

2.2. Streak Camera

The jitter of the laser micropulse is observed also with the streak camera [5,6]. In addition, sometimes, the longitudinal distribution of the micropulse deviates from a gaussian as shown in fig.3 (micropulse on the right side).

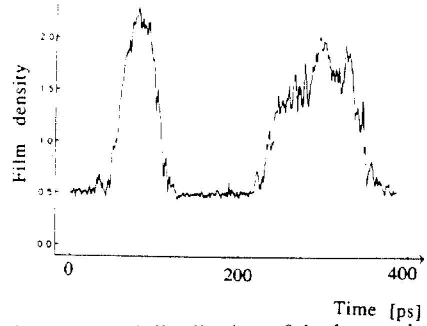

Figure 3. Temporal distribution of the laser micropulse observed by the streak camera. Vertical axis corresponds to the logarithm of luminosity and two micropulses are taken on one film.

The laser micropulses in the cw mode and the Q-switched mode are observed. The function of the Q-switching is realized by modulating the frequency of the RF cavity of the storage ring with an externally added signal of up to a few hundred Hz. Consequently, the positron bunch and the optical pulse are detuned and the laser gain is suppressed periodically. The deformation of the longitudinal distribution and the longitudinal jitter of the laser micropulse are stabilized with the Q-switching.

2.3. Summary

Even if it presents the longitudinal jitter, the laser in the zone 3 has more intensity and the narrower temporal width than the other two cw zones.

The deviation of the longitudinal distribution from a gaussian might be due to some instability of the positron beam, but further study is needed to have a clear explanation.

The Q-switched operation stabilizes the temporal features of the laser micropulse and this may be preferable to applications.

3. SPECTRAL FEATURES

3.1. Monochromator

A monochromator is an ordinal method of measuring spectrum, but it takes a few tens of seconds to complete one measurement in our case. We find the spectral width of about 1 Å (FWHM) with the monochromator. This value is averaged over a large number of laser micropulses and no dynamic behavior is observed. However, by detecting a fringe of a spontaneous emission with the monochromator, we can know a beam energy change in real time.

3.2. Scanning Fabry-Perot Interferometer

We realize a very rapid spectral measurement with a scanning Fabry-Perot to study dynamic behaviors of the laser.

One of the two mirrors which consists the interferometer is moved by piezo motors at the micron order, and according to the distance variation between two mirrors, the resonant condition of the Fabry-Perot interferometer changes, and thus we can survey the laser spectrum. The obtained laser spectrum and the temporal distribution of the micropulse are shown in fig.4, where three resonant peaks, separated by the free spectral range, appear for one lasing ray.

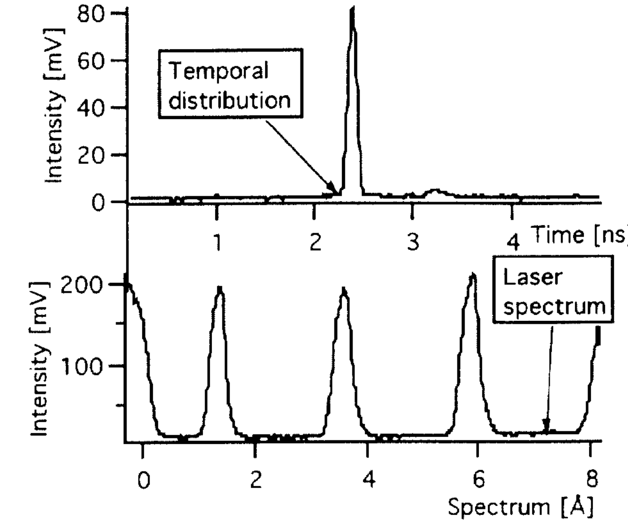

Figure 4. Temporal distribution of the laser micropulse and laser spectrum, which are simultaneously obtained by the dissector and the scanning Fabry-Perot respectively.

Fig.5 shows the variation of the lasing wavelength during a few tens of minutes. In some cases, the laser shows a slow drift of the wavelength. This drift might be related to the beam energy variation or the beam orbit change.

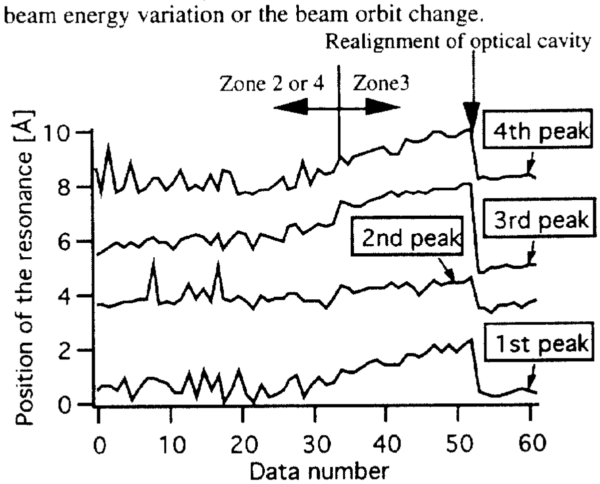

Figure 5. Drift of the lasing wavelength. Data number corresponds to time arbitrally. One scan includes four resonant points in this case.

In the cw zones 3 and 5, the spectral width stays almost constant as a function of the micropulse intensity, and a narrower spectrum is obtained for the zone 3 laser. On the contrary, in the pulsed zone 2, the laser spectral width becomes smaller as the laser intensity grows up.

We correlate the spectral and temporal features of the laser by synchronizing the scanning Fabry-Perot and the dissector. Fig.6 is the preliminary result. The spectral width does not change or it even increases for the larger temporal width. This can be understandable by the fact that the coherent length of the UV FEL is much shorter than the micropulse duration.

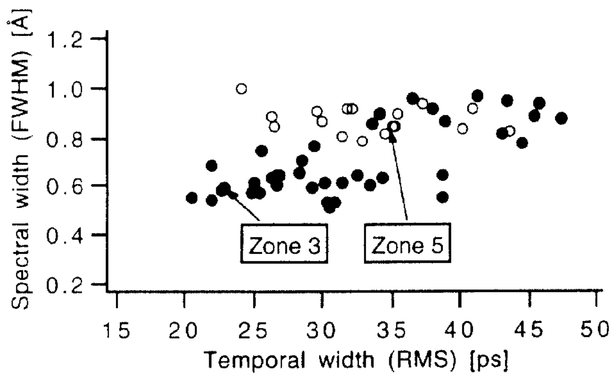

Figure 6. Temporal and spectral width of the laser micropulse in zones 3 and 5.

3.3. Summary

The stable spectral width of the laser is obtained in the cw zones, and the laser in the zone 3 has the narrowest spectrum. The spectrum evolves rapidly in the pulsed zones. The correlated measurement between the wavelength drift and the beam energy change is planned using the monochromator and the scanning Fabry-Perot. The spectral features of the laser are summarized in table 2.

Table 2
Measured spectral width and wavelength drift of the laser

Operation zone	Drift of lasing wavelength	Spectral width (FWHM)
Zone 3 (cw)	Less than 1Å	0.5~1Å
Zone 1 and 5 (cw)	Less than 1Å	0.8~1.1Å
Zone 2 and 4 (pulsed)	2 ~ 3 Å rapid drift	0.5~1.2Å spectral evolution

4. LONGITUDINAL FEEDBACK

A longitudinal feedback system is developed for operating FEL under the perfect tuning condition in the zone 3. The longitudinal position of the laser micropulse against the reference position of the positron bunch is detected with the dissector. The external modulation, which corresponds to the distance between two positions, is applied onto the RF frequency of the storage ring for adjusting the position of the laser micropulse to that of the positron bunch.

This system works very effectively [fig. 7], and the jitter and the drift of the laser wavelength are dramatically reduced in the zone 3.

5. CONCLUSIONS

We investigate the spectral and temporal behaviors of our FEL dynamically.

Although there is the temporal jitter of the laser micropulse, the laser operation in the zone 3 gives the finest spectral and temporal structure with maximum laser intensity.

The deformation of the laser micopulse distribution can be observed with the streak camera. The laser presents a wavelength drift in some cases.

The newly developed feedback system succeeds to suppress the longitudinal jitter of low frequency and the wavelength drift of the laser in the zone 3. This system has the possibility to remarkably improve the laser characteristics.

The Q-switched operation may be suitable for the applications which demand a powerful and pulsed laser at the msec scale.

A theoretical model is under developing to clarify the observed phenomena and laser mechanism.

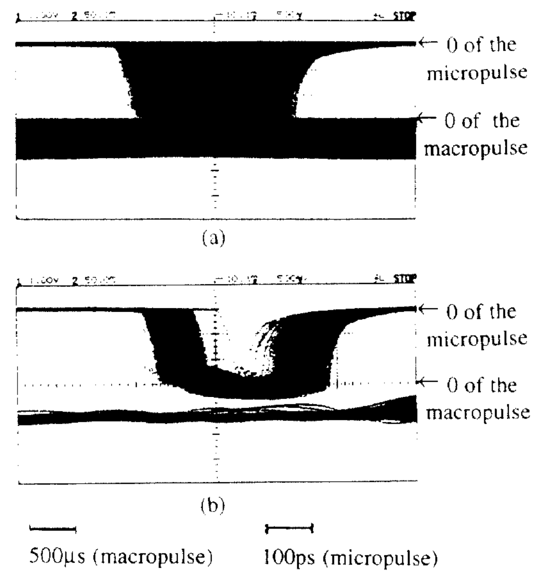

Figure 7. Laser micropulse and macropulse, (a) with the feedback off, and (b) with the feedback on. The upper channel shows the laser micropulse and its jitter, and the lower channel shows the laser macropulse. Data are accumulated by an oscillo scope for one minute. All signals are negative.

6. REFERENCES

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