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FEL WAVELENGTH JITTER DUE TO ELECTRON BEAM INSTABILITY

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Abstract : A 1.0% wavelength jitter of 10μm FEL is observed due to the electron beam instability of the order of 10%, although the FEL wavelength is usually controlled within 0.05% at FELI. During cavity detuning for the 10μm FEL the two kind of the wavelength spectrum are observed; one is the original 10μm peak and the other is twin peak (original one and more longer wavelength one). The wavelength instability is thought to be depended on the electron energy perturbation in one macropulse.

1. Introduction

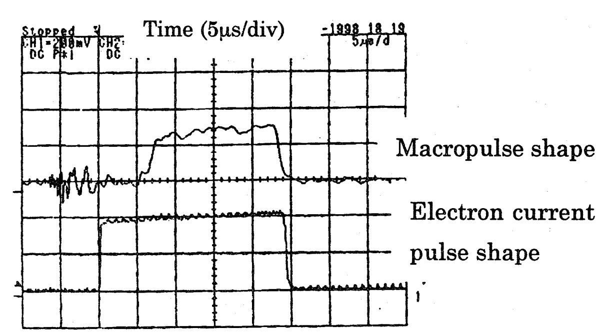
A 1.0% wavelength jitter (shift) of the 10μmFEL is observed at the FELI, although the FELI FEL wavelength jitter is usually controlled within less than 0.05% of the wavelength. The wavelength jitter is unwanted phenomena for the FEL application research, although the wavelength tunability is a unique feature of the FEL. The FEL wavelength is in principle decided with accelerated electron energy and a magnetic field in an undulator, and the wavelength can be changed by one octave within several seconds, when the undulator gap is varied.

The FELI has a 165MeV S-band linac with a thermionic type electron gun (e-gun) and four FEL facilities (FEL-1~FEL-4), which are composed of the undulators and the optical cavities, opened for user. The four facilities have been in succession opened for users since the mid-IR FEL (FEL-1) was succeeded in oscillation in 1994, and the total operation time reaches to 4800hours in 1996 and 1997 [1].

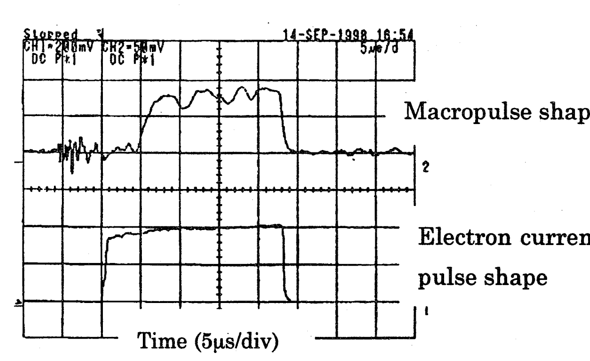
The e-gun has been replaced new one about every year as planned. It is because the stable FEL has to be supplied for applications to suppress FEL wavelength jitter due to the electron gun instability. In this paper we describe the FEL wavelength jitter due to the electron beam instability.

2. Electron instability

The emission current of the electron gun is measured fluctuates in less than 10% at an abnormal condition, although the usual variation at a normal condition is suppressed in less than 0.02%. Fig.1 shows an FEL macropulse shape and an electron current pulse shape at each condition.



(a) Normal condition



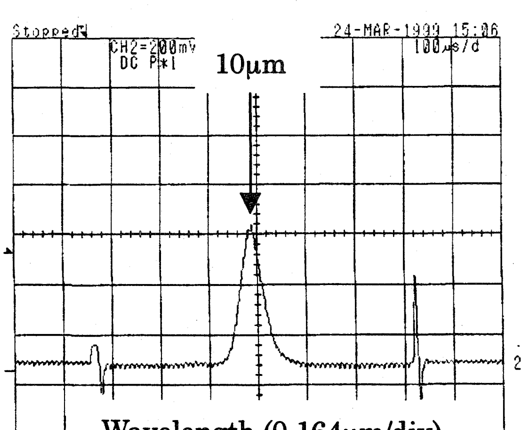
(b) Abnormal condition

Fig.1 The macropulse shape (upper) and the electron pulse shape (lower) of the 10μm FEL. (a) Normal condition (b) Abnormal condition.

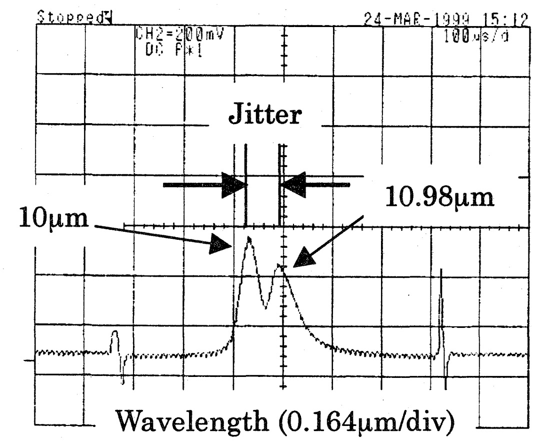
The FEL macropulse shape is measured with a HgCdTe detector in a monitor room and the electron current pulse shape is measured with a button monitor [2] at the entrance of the FEL-1 undulator. To discuss how the e-gun trouble is occurred and effect on the electron beam instability is beyond this paper, however the fluctuation of the FEL macropulse shape and a slightly deformed electron current pulse shape are pointed out and discussed at the two FEL oscillation condition.

3. Cavity detuning

Fig.2 indicates two spectra of the 10μm FEL at the abnormal condition, when they are measured at different cavity lengths of the optical resonator corresponding to (a) at a medium average power and (b) at a near maximum average power. The former spectrum (a) and the latter one (b) indicate one peak shape and a twin peak shape, respectively. The latter shape is formed from the mixture of the original 10μm peak and the slightly longer wavelength peak (10.98μm). Each peaks of the latter case have the same pulse width as one of the former case. We therefore define and calculate the wavelength jitter as a peak shift in this paper.



(a) Medium average power



(b) Near maximum average power

Fig.2 Two spectrum of 10μm FEL spectrum corresponding to the medium power and near maximum power.

The distance between a coupled resonator mirrors (cavity length) can be changed in micron meter order, and a plot curve of relation between the length and the FEL average power is called "detuning curve". The detuning curve at the normal condition was measured at the FELI [3]. The measurement suggests the detuning ranges are 150μm at the 9.2μm FEL and 80μm at the 6.5μm FEL, when the FEL has only 0.05% wavelength jitter and $\Delta\lambda/\lambda$ (FWHM) = 0.5% [3,4]. Moreover the spectrum at the normal condition was only one peak shape measured [3], when the stable region is obtained. After the measurement the one peak shape and the twin peak shape spectrum are at the normal condition observed in the displacements corresponding to the maximum average power and the medium average power, respectively. (This is an opposite result to our measurement.) The CLIO group reported the similar phenomena, and they conclude the twin peak profile is side band and the main peak like the Raman effect [5,6].

Fig.3 shows the detuning curve of the 10μm FEL at the abnormal condition, when the tuning range is 32μm.

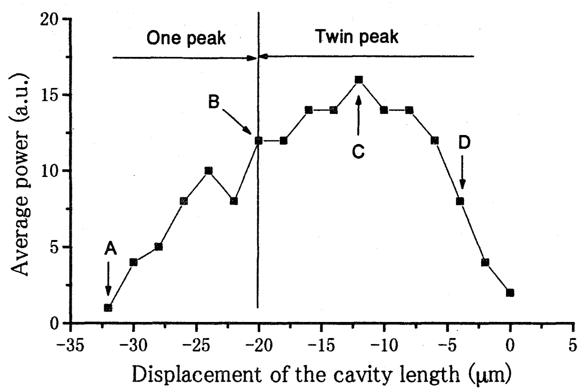


Fig.3 Detuning curve of the 10μm FEL.

In the -32 ~ -20μm displacement of cavity length the wavelength jitter is as small as one of the normal condition, although the average power is gradually increasing as the displacement decreases. In the -20 ~ 0μm region the jitter is rather large, and the spectrum shape becomes the twin peak shape.

Fig.4 shows the distributions of the 10μm FEL spectrum accumulated in 10 seconds. The marked A ~ D lines are measured at the displacements of the cavity length corresponding to the marks A ~ D shown in Fig.3. Small ripples detected in all lines are the artifact noise at the measurement.

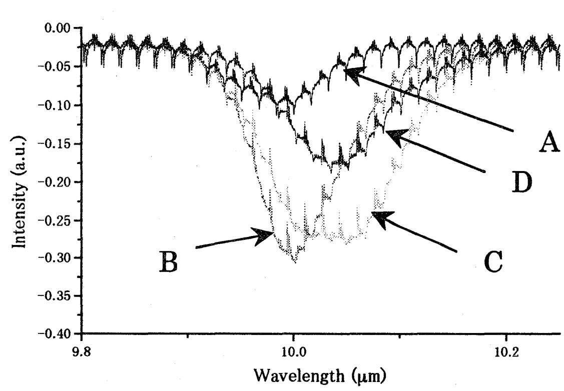


Fig.4 Spectrum of the 10μm FEL. The spectral lines marked A ~ D are corresponding to the A ~ D displacements of the cavity length described in Fig.3.

Although the spectrum peak is keeping on the 10μm line until the B displacement, the peak is shifted to the longer wavelength and looks the twin peak shape like Fig.2 (b), and the accumulated spectrum therefore represents a broad spectrum (C line or D line) in Fig.4.

The FEL wavelength depends on the energy of the accelerated electron bunch. We can say that the electron bunch has two energy parts in one macropulse which is occurred by the abnormal condition of the e-gun. The cavity detuning effects the relative position of the electron bunch and the round-trip light pulse in the resonator. The overlap of the electron bunch and the light pulse gradually shifts and the oscillating wavelength varies from the original wavelength to the longer wavelength. Measurement of time-resolved electron energy spectrum in one macropulse, which has not been measured in the FELI, will make it clear that our argument is valid or not.

4. Conclusions

We have indicated the FEL wavelength instability caused by the electron energy perturbation. Although the reason why the electron perturbation is occurred is unclear, at the abnormal condition the FEL wavelength is unstable and shifted to the longer side by 1.0% of the wavelength.

References

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